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EVALUATION OF HAZARDOUS WASTES EMPLACEMENT IN MINED OPENINGS

Ronald B. Stone, et al

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This study assesses the technical feasibility of storing nonradioactive hazardous wastes in underground mined openings. The results show that a majority of the wastes considered can be stored underground in an environmentally acceptable manner if they are properly treated and containerized. Various mine environments in the United States are applicable for such storage; room and pillar mines in salt, potash, and gypsum appear to be the most favorable. Although the underground storage and management of hazardous waste is both technically feasible and environmentally sound, further and more detailed research, including an economic evaluation, is recommended.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Municipal Environmental Research Laboratory contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The Solid and Hazardous Waste Research Division contributes to these program objectives by conducting research to promote improved solid waste management and the environmentally safe management and disposal of hazardous wastes. This report presents results of an assessment of the technical feasibility for storing nonradioactive hazardous wastes in mined openings.

Louis W. Lefke
Acting Director
Municipal Environmental
Research Laboratory

ABSTRACT

This study assesses the technical feasibility of storing non-radioactive hazardous wastes in underground mined openings. The results show that a majority of the wastes considered can be stored underground in an environmentally acceptable manner if they are properly treated and containerized. Various mine environments in the United States are applicable for such storage; room and pillar mines in salt, potash, and gypsum appear to be the most favorable. Although the underground storage and management of hazardous waste is both technically feasible and environmentally sound, further and more detailed research, including an economic evaluation, is recommended.

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SECTION 1

CONCLUSIONS

1. Storage in underground mines is an environmentally acceptable method of managing hazardous industrial wastes provided the recommended procedures of site selection, treatment, containerization, and waste handling are followed.
2. Environmentally suitable underground space for the storage of hazardous industrial wastes now exists within the United States.
3. Room and pillar mines in salt, potash, and/or gypsum offer the most suitable containment with respect to the study criteria.
4. The first-level chemical interaction of storable hazardous industrial wastes with each other or with the receiving geological formations will not create any uncontrollable situations.
5. The potential for waste migration out of a properly selected mine is slight and can be controlled through proper treatment, containerization, and site selection.
6. Systems adequate to detect, monitor, and control waste migration can be developed from current technology.
7. A need for legislation concerning the storage of hazardous industrial waste in underground mines is indicated.
8. The design and operation of an underground storage facility for hazardous industrial wastes is technically feasible.
9. Locating regional waste storage facilities at existing mines is technically feasible.
10. Additional and more detailed research is needed to close existing knowledge and technology gaps. It is estimated that such research would range from 2.3 to 3.2 million dollars.

SECTION 2

RECOMMENDATIONS

1. A study of the economic feasibility of storing and managing hazardous industrial waste in underground mines should be conducted.

2. A physical and geological evaluation of the environmental suitability of each potential storage site for hazardous industrial wastes should be conducted according to the criteria and techniques outlined in this study.

3. An assessment of public attitudes, mine owner attitudes, and environmental impact must be conducted for each potential waste storage site.

4. A detailed evaluation of the composition, properties, treatment procedures, and volumes of hazardous industrial waste-streams as they actually occur from industry should be conducted.

5. A study should be conducted to determine the best type of containerization or encapsulation to protect the environment from any possible contamination resulting from handling or underground storage of hazardous industrial wastes.

6. Since it was not possible within the scope of this study, to investigate beyond the first-level chemical interaction of the storable wastes with each other or with the receiving geological formations, a study of all possible subsequent chain reactions should be conducted.

7. Due to the unique physical nature of each mine site, it was not possible to investigate the environmental effects of waste migration for particular sites. Although migration is considered unlikely, it is recommended that such a study be conducted.

8. Optimum systems should be developed for detecting, monitoring, and controlling the wastes.

9. If the concept of storing and managing hazardous industrial wastes

underground is accepted, safety and controlling legislation will be required.

10. If an economic evaluation is favorable, a demonstration facility should be designed, constructed and operated to confirm operating principles and costs.

SECTION 3

SUMMARY

The practice of using salt and other deposits to store and securely isolate many types of industrial products, especially hydrocarbon liquids and gases, has existed for over 40 years. Absolute containment of these products is necessitated by both economic and environmental considerations. Salt, potash, and gypsum are increasingly attractive as mediums for safe, long-term isolation of environmentally hazardous substances. Recently, salt has been utilized as a repository for low-level radioactive wastes and it is currently being investigated for high-level nuclear waste storage. In addition, it has received attention as a favorable storage medium for extremely hazardous, chemical warfare munitions.

The potential for hazardous wastes stored underground to be carried out of a mine in either air or ground water must be minimized to protect both the surface and subsurface environments. To accomplish this, basic criteria were established which had to be met before an acceptable level of environmental protection could be assured. These include: geologic stability in and around an underground facility; hydrologic and surface isolation; chemical compatibility of the stored wastes with each other and the host-medium; personnel safety underground; and long-term flexibility to meet changing conditions. The results and conclusions reached during the course of this preliminary investigation are summarized below.

Salt is widely distributed in the United States, thus risks resulting from long distance transport of hazardous material can be reduced. It occurs in massive deposits and is readily mined. In several regions of the United States large volume underground openings presently exist. Salt usually occurs in areas of low seismic risk and long geologic stability. Salt has good structural properties including high compressive strength (comparable to concrete) and plasticity, which acts to naturally heal fractures and passively relieve stress. Salt is essentially impervious and free of circulating ground water. It is typically well isolated from all underground aquifers by adjacent thick and impervious deposits. Chemically, salt is compatible with nearly all of the investigated hazardous compounds, and the few exceptions can be treated or otherwise controlled for acceptable storage.

Mined openings in salt are typically large, nearly horizontal, and relatively stable. Problems are rare, usually resulting from excessive extraction which overloads the supporting pillars, or water leakage down the shafts; both are controllable using available means. Temperature and humidity in salt openings are usually moderate and quite stable. The present volume of mined space existing in salt formations in the United States greatly exceeds the estimated volume of hazardous industrial wastes, and new space is constantly being created in operating mines.

Domal salt has structural qualities similar to bedded salt but occurs as isolated intrusions primarily in the Gulf Coast Region of the United States. Mines in salt domes are typically more susceptible to water problems, both above and below the surface.

Potash salts are extensively mined in southeastern New Mexico, but present extraction is accomplished in a manner that leaves little usable space.

Gypsum would be an excellent host-medium on the basis of chemical compatibility with the wastes. However, most gypsum mines are poorly isolated from both the surface and near surface water. Carefully chosen existing mines or new mines could be sited to provide acceptable environmental protection while storing hazardous industrial wastes.

Limestone has good potential as a storage medium by virtue of the many existing mined openings in widespread regions of the United States. Underground limestone formations are occasionally well isolated from ground water; but more commonly, fracture permeability and solubility allow water to enter openings, especially in wet climatic regions.

Shales could be suitable for hazardous waste emplacement, provided they are low in expanding clays. A potential benefit of shales is their high ion-exchange capacity which acts both to limit migration and reduce toxicity. Shales are not commonly mined and they usually present certain structural problems. However, they are widely distributed, essentially impervious and commonly well isolated from migrating ground water.

In selected areas presently lacking underground space, new waste storage mines constructed in granite are feasible. Granite is exceptionally strong, and unless fractured or faulted, is impervious to water. Seismicity, local structure, and present lack of mined space are the primary limitations to its use as a host-medium for hazardous industrial wastes. Strongly acidic or basic solutions might be structurally debilitating to granite over a long period of time.

The hazardous characteristics of wastes found to be unacceptable in the closed confines of an underground opening include flammability, explosiveness, and gas evolution. Of the noxious wastes studied, more than

99 percent of the total volume produced can be safely stored underground after treatment. Mercury compounds had to be completely rejected for underground storage because their toxicity could not be sufficiently reduced using known treatment procedures; however, it was found that their use in industry is declining. Five other wastes were tentatively rejected pending additional data for evaluation.

Tables showing waste classifications by treatment and acceptability are presented in Section 6 of this report.

Certain wastes will present less risk if stored separately; the use of specific areas within a mine for storing compatible waste groups, plus bulkheads and other special isolation techniques, will eliminate potential problems of waste interaction.

Encapsulation and/or containerization will additionally insure against waste migration or interaction, while at the same time, protecting workers and facilitating placement and/or retrieval of the wastes.

The design and operation of an underground waste facility using selected existing mines or new openings can be achieved using existing technology. Methods required to monitor the underground and surface environments have been reviewed, and available instruments will provide good control over all critical factors.

Legislation will be needed to control the use and operation of an underground facility for hazardous waste storage.

Economic studies are needed to assess the practical feasibility of underground storage. Such studies will have to include a detailed cost/benefit evaluation of using either operating mines, new mines, or abandoned mines, or combinations thereof.

By using a technical/environmental approach, the feasibility of safely storing, controlling, and managing hazardous industrial wastes in selected underground openings has been demonstrated. Underground space can provide excellent waste isolation and control, with genuine protection to the biosphere. The potential for migration under any conceivable circumstances is essentially eliminated by the natural characteristics of a carefully selected underground environment.

Many other industrial wastes, which were not included in this initial study because they were considered less hazardous to the biosphere, might also become candidates for this type of storage after detailed cost/risk evaluations are made. Similarly, the acceptance of greater risks by reducing treatment levels, less containerization, and/or storing presently untreatable toxic wastes, could substantially alter the economics of storing hazardous industrial wastes in mines. Within the limited scope of this study, alternatives such as these could not be specifically addressed; however, this investigation does provide a basis for development of future options.

SECTION 4

INTRODUCTION

The use of underground space as a storage medium is receiving increased attention throughout the United States. The cost-benefit ratio of using a mined facility versus that of a comparative surface facility is enticing enough that both government and industry are seriously considering mined space as one answer to their storage problems. Mined space is presently being used for the dry storage of movie film, microfilm, computer tapes, bank records, and civil defense commodities. In addition, industry presently uses mined openings for the storage of liquefied petroleum gas, gasoline, crude oil, natural gas, and anhydrous ammonia.

The concept of storing hazardous wastes in mined openings is not new. The United States Atomic Energy Commission is conducting extensive studies into the use of underground space for the disposal of its radioactive wastes. The Republic of Germany presently has a radioactive waste disposal facility in operation at the ASSE Salt Mine in Germany. United States industry does not presently use this method for disposing of its hazardous wastes because cheaper methods are available; however, many of these methods are environmentally unsound. Growing concern over possible degradation of the environment from current disposal methods has led government to seek more acceptable ways for industry to dispose of its hazardous wastes. Towards this end, Fenix & Scisson, Inc. of Tulsa, Oklahoma was awarded a contract under the sponsorship of the United States Environmental Protection Agency to perform an initial technical review and assessment into the use of underground space in salt and other deposits for the emplacement of hazardous industrial wastes. This report contains the results of that study.

OBJECTIVES

The primary objective of this study was to provide an assessment of the environmental acceptability of emplacing hazardous industrial wastes in underground mines. In making this assessment, the following investigations were necessary:

1. The development of geological criteria which can be used to select sites providing maximum environmental protection for the emplacement of hazardous industrial wastes.

2. The characterization of hazardous industrial wastes to determine if they could be placed in underground mines in an environmentally acceptable manner.

3. The determination of the potential for wastes to migrate from the mine environment.

4. An evaluation of the capability of existing equipment to detect, monitor, and control potential waste contamination and migration.

5. An evaluation of mine design, construction, and operating requirements necessary to ensure safe operation and complete environmental protection.

The scope of this study was to accomplish these investigations within allotted time and fund limitations using available literature, professional experience, and expert opinions. An economic evaluation of this concept was not within the scope of this contract.

PHILOSOPHY OF UNDERGROUND STORAGE

The word "disposal" is often used in referring to the emplacement of hazardous wastes in mines, and suggests that a waste is permanently emplaced without provision for controlling its long-term environmental effects. Early in this study, it was decided that a different philosophy would be more consistent with the long-term protection of the environment.

The evaluations made in this study are based upon the concept of both short and long-term storage and management of the wastes. In the short-term, mined storage would allow a hazardous waste to be isolated, continually monitored, and controlled to provide complete environmental protection. This protective quality of mined storage is augmented by the ability to retrieve the containerized wastes from storage should unacceptable conditions develop. In the long-term, the stored wastes may be looked upon as a potentially exploitable resource. As changes in technology and/or economics develop, a properly stored and managed waste could be retrieved from a mine and recycled. This aspect of mined storage might permit a facility to return some of its original investment.

With this philosophy in mind, the storage and management of hazardous industrial wastes in underground mines, if shown to be environmentally acceptable and technically feasible, will provide a solution to the immediate problem of isolating hazardous wastes from the biosphere without jeopardizing future options or benefits.

APPROACH

To fulfill the primary objective of assessing the environmental acceptability of the concept, this study was divided into the following major tasks:

1. Geological Characterization.
2. Waste Characterization.
3. Detection, Monitoring, and Control Technology.
4. Regulations Assessment.
5. Mine Design.
6. Proof-Of-Concept.

The relative organization of these tasks is outlined in Figure 1.

The study began with a concurrent review of available literature pertaining to underground mines, subsurface disposal problems, industrial waste streams, and current waste disposal or storage techniques. This literature review resulted in the identification of three major problem areas concerning waste isolation:

1. The physical and geological environment of an underground storage facility.
2. The chemical and hazardous nature of the wastes.
3. The geochemical compatibility of the wastes with mine environments.

These aspects of hazardous waste storage in mines were considered to be of primary concern in determining the environmental acceptability of the concept. However, to provide a more realistic overall assessment of the concept, it was also necessary to evaluate the following:

1. Detection, monitoring, and control technology.
2. Regulatory aspects of waste storage in mines.
3. Design of an underground waste facility.
4. A demonstration of feasibility through a proof-of-concept exercise.

Within the scope of this initial study, the economic aspects of this storage concept were not directly addressed. However, in approaching each area of the study, broad economic considerations were often unavoidable when choosing one line of investigation over another.

By an analysis of the environmental and technical problems in each of these areas, it will be determined if hazardous industrial wastes can be stored underground in an environmentally acceptable manner. Each

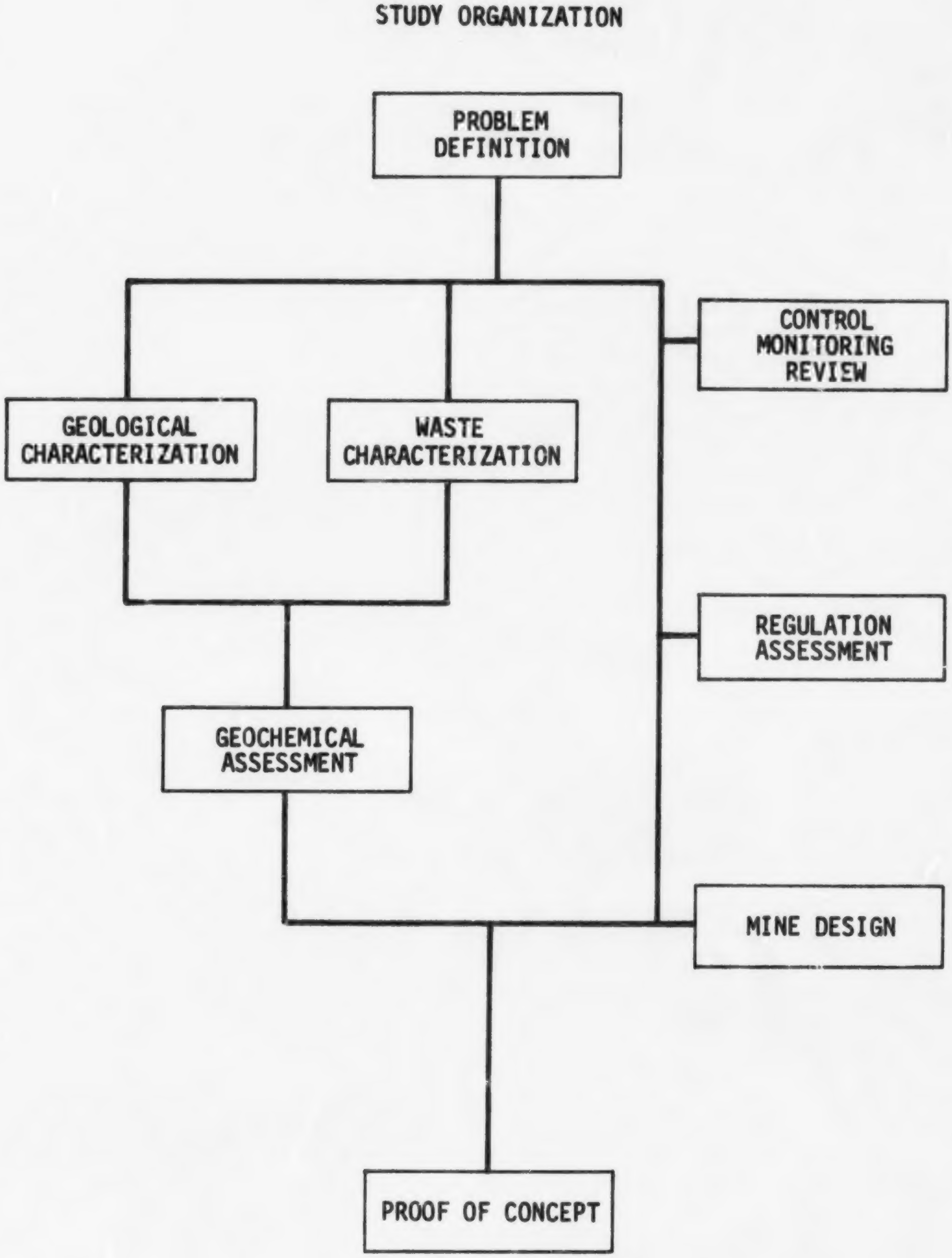

STUDY ORGANIZATION
PROBLEM DEFINITION
CONTROL MONITORING REVIEW
GEOLOGICAL CHARACTERIZATION
WASTE CHARACTERIZATION
REGULATION ASSESSMENT
GEOCHEMICAL ASSESSMENT
MINE DESIGN
PROOF OF CONCEPT

Figure 1. Study Organization.

of the major aspects of storing and managing hazardous industrial wastes in underground openings are presented in detail on the following pages.

SECTION 5

GEOLOGICAL CHARACTERIZATION

The purpose of the geological characterization was to assess the environmental suitability of underground space as a potential storage medium for hazardous industrial wastes, and to develop geological criteria which can be used to select environmentally acceptable sites.

The literature review produced a considerable amount of relevent information pertaining to underground disposal of radioactive wastes. These wastes are similar to hazardous industrial wastes because they both require total long-term isolation from the biosphere. Adddtionally, a review was made of in-house investigations and criteria previously developed for the storage of many liquid (and liquefied) petroleum products. Other similar and related research was screened and from all of these sources certain criteria were developed. These criteria, if met completely, would provide an ideal geologic environment for disposing of hazardous industrial wastes, and were used as a basic research guide for comparison of various geologic and mine environments. The criteria developed and the reasons for choosing each are listed below.

Geologic and Mine Criteria	Reason for Selection
Room and pillar design.	Provides maximum usable space, is easily compartmentalized, has excellent storage and transport utility, and mines of this design meet many of the other criteria.
Dry and impervious.	Potential for adverse reactivity is sharply reduced in a dry environment and potential for migration of soluble wastes may ultimately be controlled by permeability of the surrounding rock.
Structurally stable.	Structural stability is dictated by personnel safety, long term utility, and the need for total isolation.

Geologic and Mine Criteria	Reason for Selection
Nonreactive to wastes.	Deterioration of the structural integrity of an underground opening by unfavorable chemical reaction must be avoided.
Homogeneous mineralogy.	Evaluation of both structural and chemical characteristics of a host-rock is facilitated by uniformity.
Low Seismicity.	Limit potential for damage or loss from earthquakes.
Depth less than 900 meters (3,000 ft).	Practicality of moving bulk material is reduced with depth; and increased overburden pressures from increased depth must be compensated for resulting in less usable space and/or increased stability problems. [Nominal depth for storage with good stability and insured isolation is between 183 and 366 meters (600 and 1,200 feet).]
Widespread distribution of lithology or mined deposit.	The need for large-volume storage at several geographic locations.
Near-horizontal bedding.	Problems of storage and underground transport of wastes are reduced.
Single level opening.	Underground storage, transport, and control of the wastes are facilitated.
Accessible to transportation.	A basic requirement of any storage site is that the wastes must be transported safely from their source to the facility on a year-round basis. The surface area above the mined facility should be such that necessary aboveground facilities can be constructed.

Each of the above criteria can be separated into lesser components and in many cases, it was expedient to evaluate these individual components in order to arrive at a broad evaluation.

The basic lithologies were selected early in the study on the basis of known characteristics and physical occurrence. Salt, having received the greatest previous attention as a waste disposal medium, was of primary interest. Other evaporites (gypsum and potash) were investigated due to their similarity, occurrence, and development. Certain other lithologies were selected on the basis of their proven storage potential of hydrocarbon products, geographic occurrence, minability, and general characteristics.

Limestones were considered because they occur in many areas of the United States, are often mined, and appeared to satisfy many of the geologic and mine criteria. In addition, by determining the suitability of limestone, certain other related lithologies would also be indirectly considered, the most important of these being dolomites which are generally stronger, commonly mined, and widely distributed.

Shales were chosen due to their widespread occurrence and potential for beneficial reactions (ion exchange capacity) with the wastes. Although not commonly mined, shales are generally impervious and have been successfully used for the storage of liquid petroleum products.

Granite, as a rock type is less uniform (homogeneous) than the other selected lithologies, is not typically mined by room and pillar methods, and is often associated with mountainous terrain. On the other hand, it is a very competent lithology, and is essentially impervious except where locally fractured. It is not easily weathered, which implies little reactivity to weathering agents, occurs in large geographic areas and has been mined by room and pillar methods for hydrocarbon storage.

When selecting the lithologies, it was recognized that general lithologic characterizations are not wholly practical or realistic, but to best meet the study objectives certain generalizations were required. The lithologies that have been considered in this study are believed to be the most promising, however, this list is not restrictive and other lithologic environments could reasonably be added as required.

The following discussions analyze each of the selected lithologies in detail. An evaluation of their environmental suitability for hazardous waste storage is presented at the end of this section.

SALT ENVIRONMENTS

Major salt deposits occur in many areas of the continental United States, both as bedded units within large sedimentary basins and as diapiric domes. Many of the natural salt deposits have been or are currently being mined, thus, are considered potential sites for hazardous waste disposal. Figure 2 shows the major United States salt deposits and salt mine locations.

PREVIOUS INVESTIGATIONS

Over the past fifteen to twenty years, salt deposits have received increasing study as possible repositories for very long-term isolation of hazardous (nuclear and chemical warfare) wastes. These investigations provide volumes of information about natural salt deposits, much of which is favorable to the concept of using salt to store and isolate hazardous wastes from the biosphere. Many of the conclusions reached in these previous studies will be utilized in this report without elaboration.

Although a majority of past research has been oriented to the problems of radioactive and military waste storage, the problems of storing noxious industrial wastes are similar in that they must also be isolated from the biosphere for very long times. Furthermore, all of these wastes have the potential to be carried in migrating ground water, so they must be effectively isolated from aquifers if stored underground. Finally, industrial waste streams will very likely contain material having future economic value and thus the benefits of long-term retrieval must be considered.

Salt deposits have been prime disposal site candidates from the inception of studies conducted to evaluate underground storage of hazardous wastes. Certain characteristics of both bedded and diapiric salt deposits are very attractive when considering long term isolation. Generally, these can be summarized as: stability, strength, impermeability, plasticity, gross volume, and areal distribution.

The stability of a salt deposit includes consideration of its seismic susceptability, faulting, rock strength, and rate of dissolution, plus any other factors bearing on its potential for future alteration. Since the geologic environment is not static, stability is a relative term for describing the rates of change for an area or formation.

Salt deposits found in the continental United States are typically located in "low risk" seismic regions. Figure 3 outlines the major seismic areas and fault zones in the United States. Faulting in salt areas is usually a local occurrence and not directly attributable to large regional tectonic zones. Bedded salt deposits are commonly located in large sedimentary basins which represent millions of years of deposition and thus exhibit good relative stability. Salt domes are associated with younger emergent land and probably represent diapiric intrusion of originally thick bedded salt along weak structural zones due to the increasing overburden pressure. By the nature of their occurrence, salt domes are more dynamic than bedded salt deposits, but they also occur in areas of low seismic risk. Geological investiga-

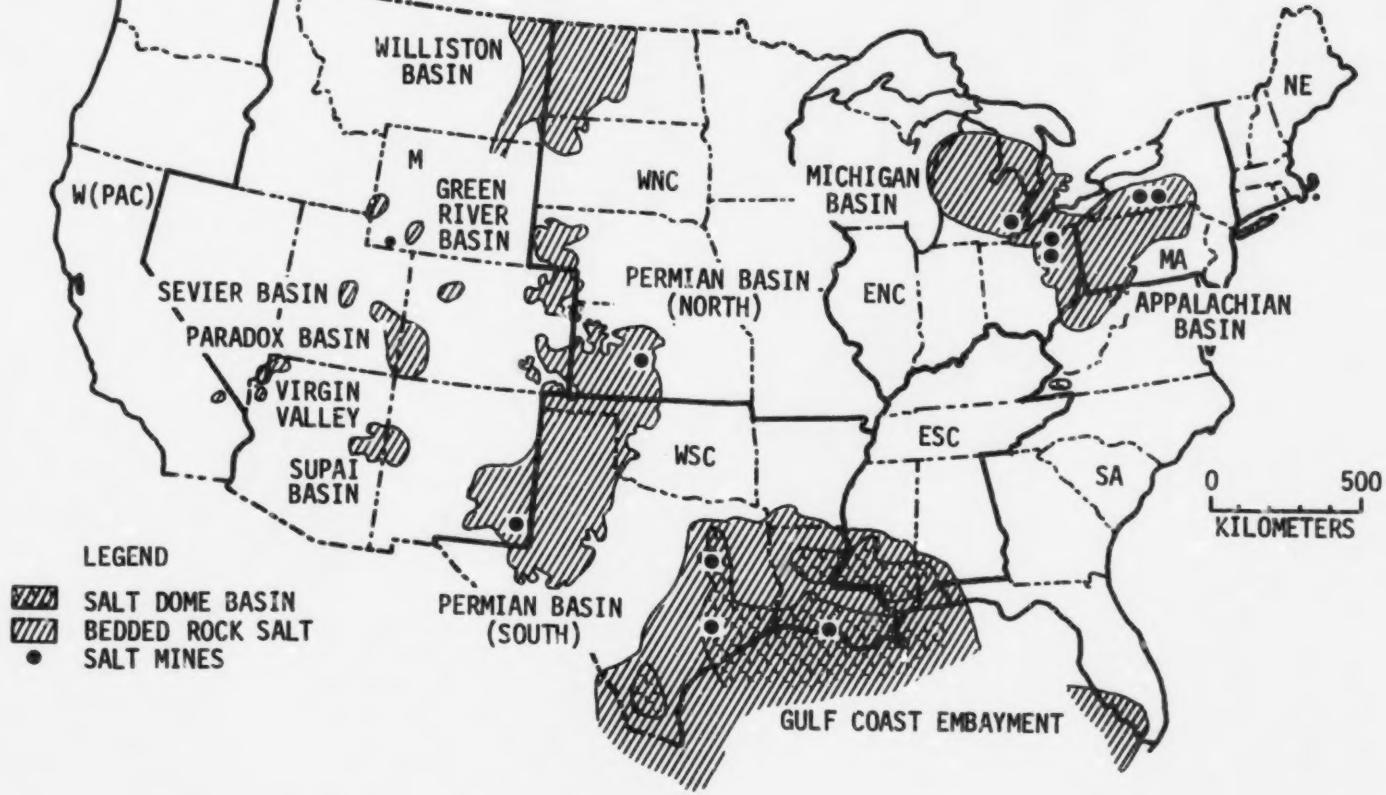

WILLISTON BASIN
NE
M
GREEN RIVER BASIN
WNC
MICHIGAN BASIN
W(PAC)
SEVIER BASIN
PERMIAN BASIN (NORTH)
ENC
MA
APPALACHIAN BASIN
PARADOX BASIN
VIRGIN VALLEY
ESC
WSC
SA
SUPAI BASIN
0 500 KILOMETERS
LEGEND
▨ SALT DOME BASIN
▨ BEDDED ROCK SALT
● SALT MINES
PERMIAN BASIN (SOUTH)
GULF COAST EMBAYMENT

Figure 2. Major United States Salt Deposits and Mines.

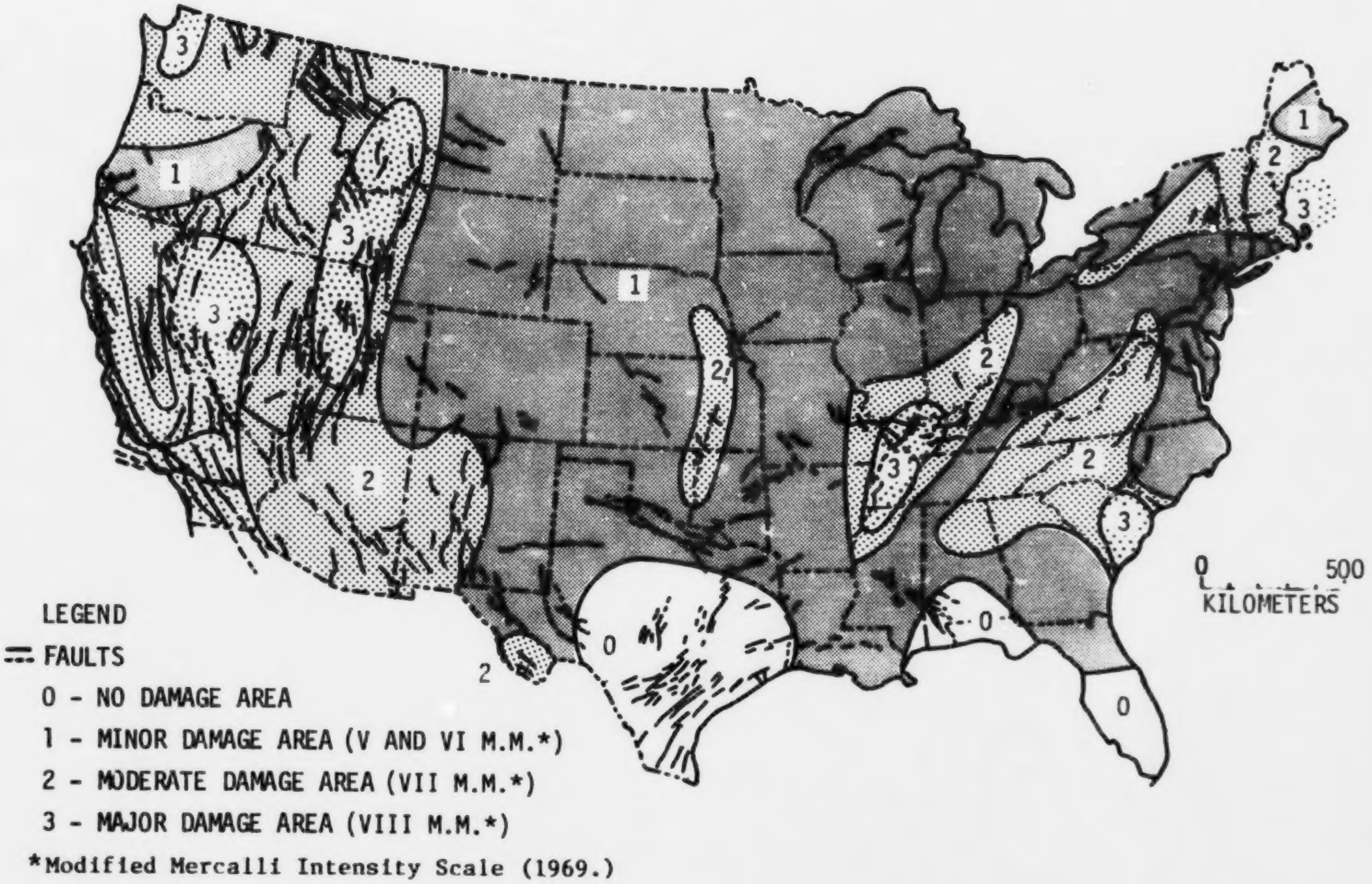

3
1
3
3
2
1
2
2
2
3
2
3
1
2
3
0
0
0
2
0
500
KILOMETERS
LEGEND
FAULTS
0 - NO DAMAGE AREA
1 - MINOR DAMAGE AREA (V AND VI M.M.*)
2 - MODERATE DAMAGE AREA (VII M.M.*)
3 - MAJOR DAMAGE AREA (VIII M.M.*)
*Modified Mercalli Intensity Scale (1969.)

Figure 3. Seismic Risk Areas and Fault Zones in the United States.

tions in the Gulf Coast region indicate that the interior domes are older and more stable than the coastal domes, many of which may still be actively rising.

The strength of rock salt in situ, is quite good and has been compared to the strength of concrete. Compressive strength values for bedded and domal salts are consistently much greater than their tensional strengths when tested in the laboratory. The plastic behavior of salt under pressure permits absorption and dispersal of strain and thus is a very important and beneficial structural characteristic.

The rate of dissolution of salt deposits is controlled by local ground water conditions. By being impermeable, salt is a barrier to ground water, yet it often occurs in proximity to water-bearing strata. The major underground hydrologic basins are shown in Figure 4. The rate of dissolution is highly variable being dependent on the rate of flow, carrying capacity of the water (previous saturation), purity, solubility of the salt formation, etc. Investigations to determine dissolution rates of individual salt deposits have been limited to special area studies and indicate that the major salt deposits retreat at extremely slow rates. Other factors which have affected the stability of salt have resulted from mining and drilling operations. Drill holes that penetrate bedded salt deposits and connect aquifers above and below have occasionally been known to permit migration of water with subsequent dissolution of the intersected salt. Problems that result from man's activity can be controlled when necessary.

Rock salt is typically mined using room and pillar techniques with recovery ratios of 65 to 75 percent being common. As a general rule, the greater the recovery ratio, the less stable the mined opening. At greater depths, the recovery ratio is usually less because the increased compressive forces of the overburden require additional support.

Mined salt deposits contain very pure sodium chloride with minor amounts of anhydrite, related salts, and shales. These contaminants usually don't exceed five percent of the total composition. Very minor amounts of interstitial water and gases (commonly carbon dioxide or methane) may also exist but do not cause problems in mining. Salt domes are generally purer than bedded salt deposits, possibly due to a natural "refining" of the domal salt during intrusion. Similarly, younger coastal domes are purer than the older, and shallower interior domes.

The purity of naturally occurring salt is in large part responsible for its highly impermeable nature, thus is important when considering plastic deformation which acts to close permeable openings. In general, contaminants reduce the plasticity of salt and act to reduce its self-healing potential. The inherent imperviousness of salt, whether bedded or domed, is often enhanced by associated impermeable rock either as discreet intervals above, below, or within bedded deposits or as a cap-

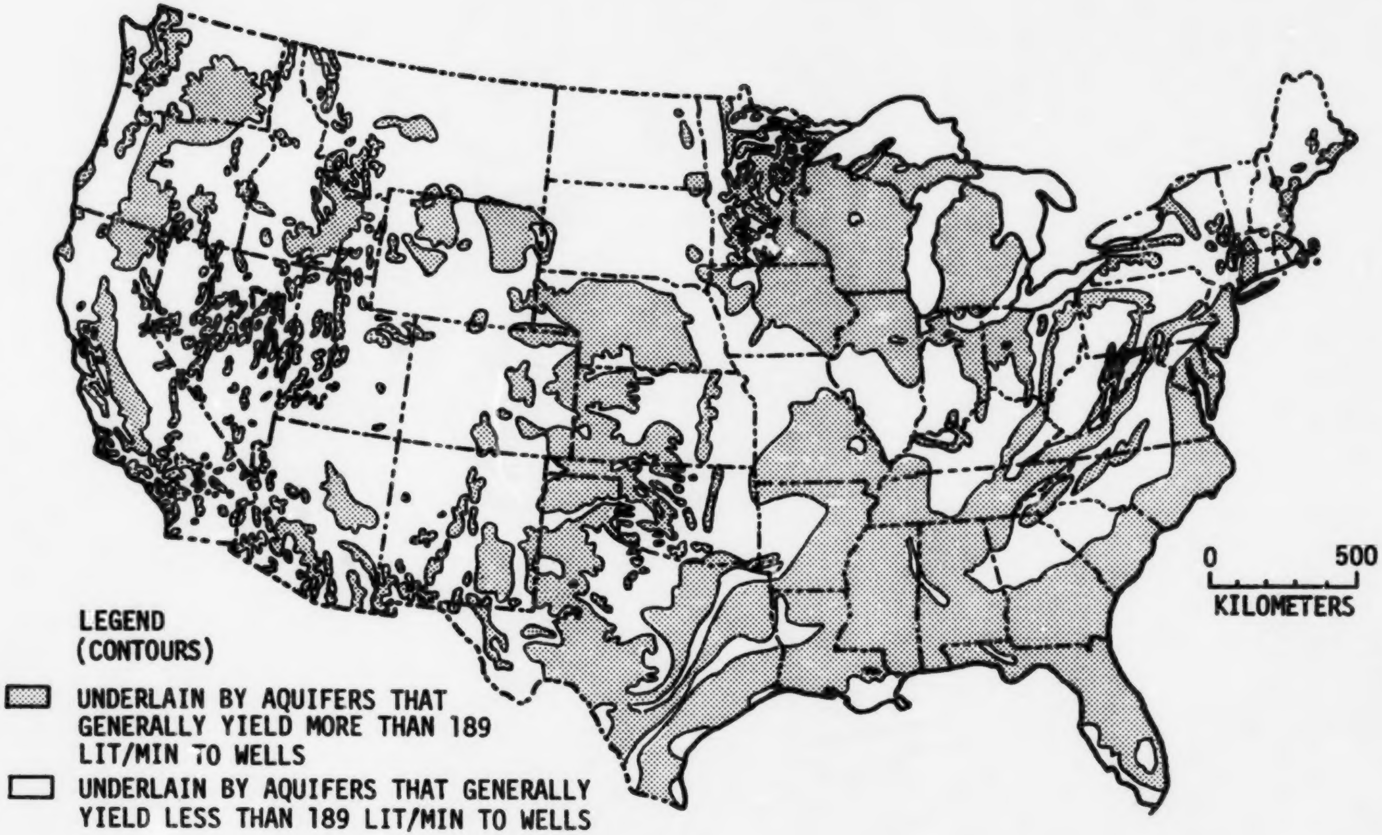

LEGEND
(CONTOURS)
▨ UNDERLAIN BY AQUIFERS THAT GENERALLY YIELD MORE THAN 189 LIT/MIN TO WELLS
☐ UNDERLAIN BY AQUIFERS THAT GENERALLY YIELD LESS THAN 189 LIT/MIN TO WELLS
0
500
KILOMETERS

Figure 4. Major Aquifers in the United States.

rock over salt domes. For this reason, a review of all surrounding strata is an integral part of any analysis of the migration potential of wastes which could be carried in ground water.

The long-range effects of a changing climate might result in either increased or reduced glaciation and a subsequent rise of ocean levels. Figure 5 shows the major salt areas which would be affected by extreme changes in either condition. Both changes would require thousands of years to develop at natural rates, and thus their importance is limited to long-range planning.

Although salt is important economically, there are huge reserves in several areas of the United States. The large volume of these reserves, their widespread distribution, and their related mining operations means that the potential storage space is enormous, economic value need not be sacrificed, and future reserves will not be affected by the use of space in salt for hazardous waste storage.

Conventionally Mined Salt Deposits

There are five major salt producing areas in the continental United States that are being mined using conventional mining techniques. For purposes of this investigation these have been classified as:

1. The Appalachian Basin.
2. The Michigan Basin.
3. The northern Permian Basin.
4. The southern Permian Basin.
5. The Gulf Coast Embayment.

The Appalachian Basin, underlying parts of New York, Pennsylvania, West Virginia, and Ohio, contains several salt beds in the Salina formation of Late Silurian age. Mining of the Salina salts is presently conducted at three sites in west-central New York State, and at two sites in northern Ohio.

The Michigan Basin contains contiguous Late Silurian deposits separated from the Appalachian Basin by the Findley Arch, a northeast trending uplift extending from Ohio into Canada. The Salina salts in the Michigan Basin are mined conventionally at one site in the Detroit area. Figure 6 shows the geographic extent and major structural features of the Appalachian and Michigan Basins.

The Permian Basin includes the Lower Permian salt bearing formations in Kansas, southeastern Colorado, western Oklahoma, and Texas Panhandle, and the Upper Permian formations in southwestern Texas and southeastern New Mexico. The Permian salt units are conventionally mined for salt in central Kansas, and for potash in southeastern New Mexico.

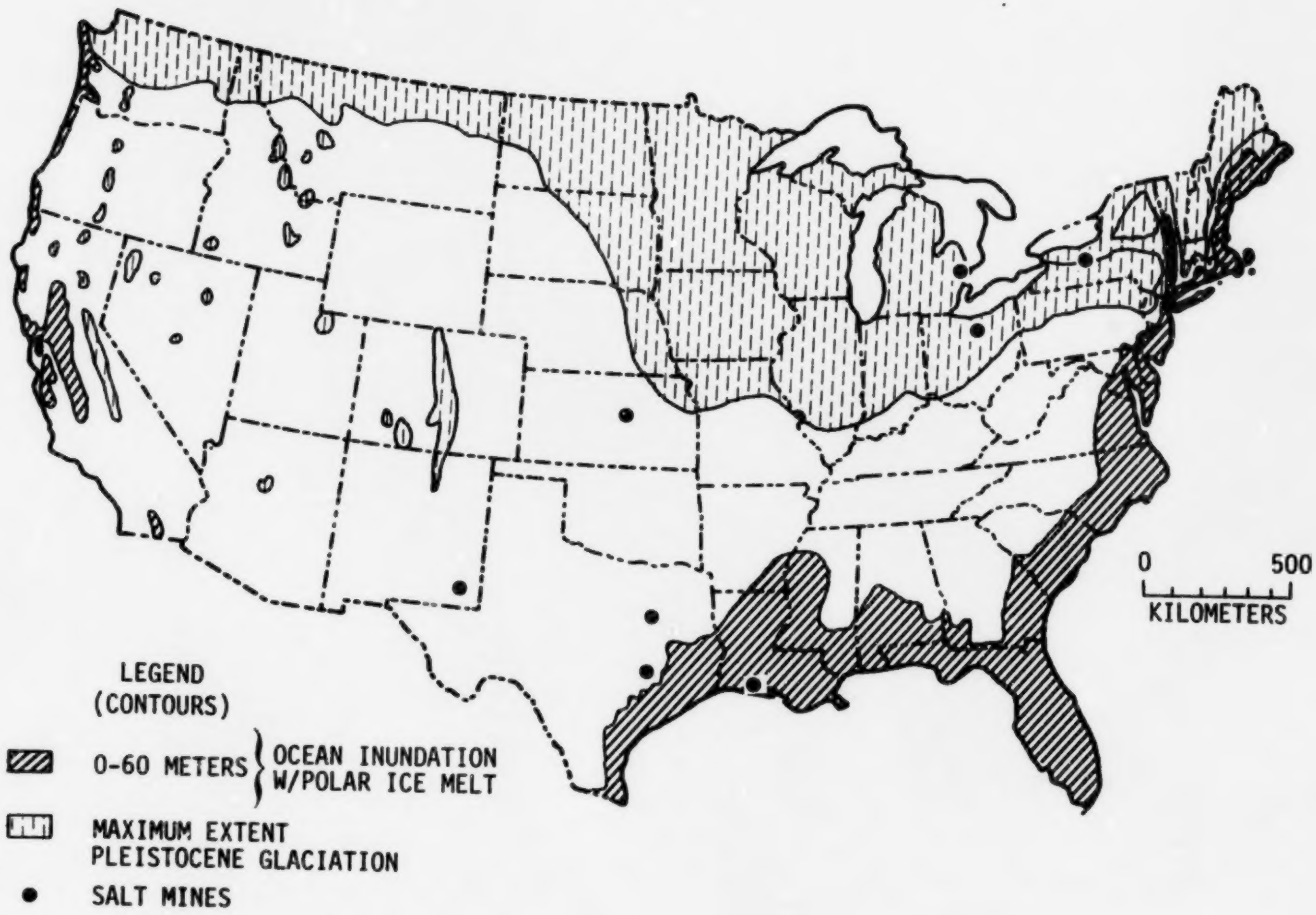

0 500
KILOMETERS
LEGEND
(CONTOURS)
▨ 0-60 METERS } OCEAN INUNDATION W/POLAR ICE MELT
MAXIMUM EXTENT PLEISTOCENE GLACIATION
● SALT MINES

Figure 5. Effects of Glaciation or Sea Level Rise in the United States.

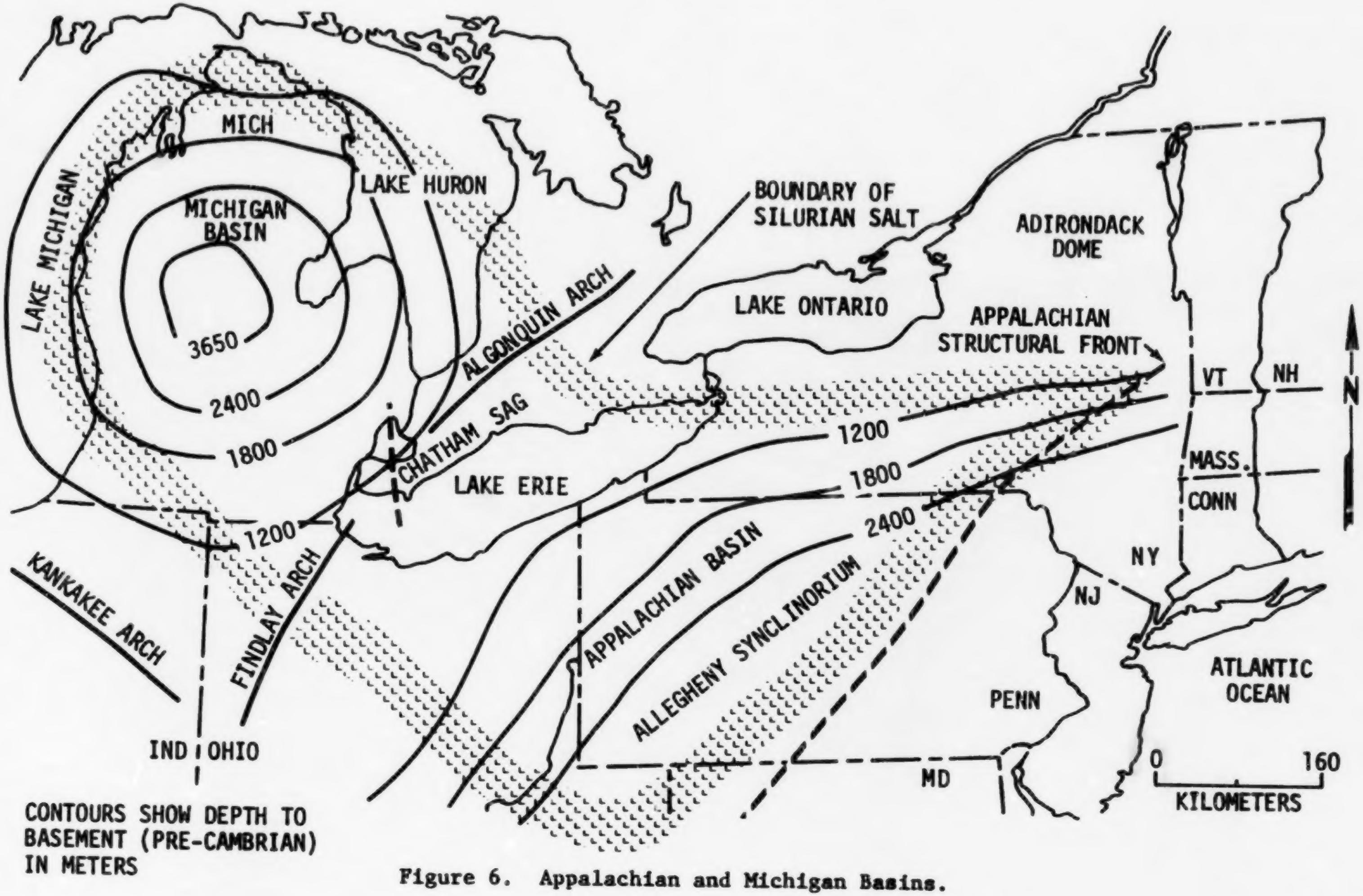

MICH
LAKE MICHIGAN
MICHIGAN BASIN
3650
2400
1800
1200
LAKE HURON
ALGONQUIN ARCH
CHATHAM SAG
LAKE ERIE
BOUNDARY OF SILURIAN SALT
LAKE ONTARIO
ADIRONDACK DOME
APPALACHIAN STRUCTURAL FRONT
1200
1800
2400
APPALACHIAN BASIN
ALLEGHENY SYNCLINORIUM
KANKAKEE ARCH
FINDLAY ARCH
IND
OHIO
PENN
MD
NJ
NY
VT
NH
MASS.
CONN
ATLANTIC OCEAN
N
0
160
KILOMETERS
CONTOURS SHOW DEPTH TO BASEMENT (PRE-CAMBRIAN) IN METERS

Figure 6. Appalachian and Michigan Basins.

The fifth major area having conventionally mined salt is known as the Gulf Coast Embayment which is divided into the interior salt dome region and the coastal salt dome region. The salt deposits throughout this area occur as diapiric intrusions which originated from the Louann salt bed, a thick unit within the Jurassic Eagle Mills formation. The interior dome area extends from northeastern Texas through northern Louisiana to south-central Mississippi, and the coastal dome area extends from southeastern Texas to the Mississippi delta. Two conventional salt mines are located in Texas, and five mines are producing in southern Louisiana.

Each of the basins will be examined in more detail on the following pages. Pertinent features including stratigraphy, structure, hydrology, and seismicity will be described.

Appalachian Basin

The Appalachian Basin is composed of Paleozoic carbonates, evaporites, shales, and sandstones overlain by Pleistocene glacial drift. The regional dip of the bedded Paleozoic deposits is typically 9.5 meters per kilometer (50 feet per mile) to the south. The elongated east-west basin is bounded by the Adirondack uplift in the northeast, the Appalachian structural front in the southeast, and the Findley Arch in the northwest. The northern boundary is an east-west outcrop zone south of and roughly parallel to Lake Ontario. In central and western New York the combined thickness of the Paleozoic strata approaches 4,267 meters (14,000 feet) and includes Cambrian, Ordovician, Silurian, and Devonian aged rocks separated by nonconformable contacts.

Stratigraphy and Structure

The Silurian deposits in the Appalachian Basin include the Medina, Niagara, and Cayuga series in ascending order, with the salt bearing Salina group within the Cayuga series. The Salina group is composed of five separate formations which are, from oldest to youngest: the Pittsford shale (sometimes considered a top member of the Niagara Series), the Vernon shale, the Syracuse salt, the Camillus shale, and the Bertie limestone. The Salina Group in the Appalachian Basin is up to 760 meters (2,500 feet) thick. Its greatest thickness is in northeastern Pennsylvania which is near the center of the Appalachian Basin.

The Syracuse Formation in New York ranges from 0 to 395 meters (1,300 feet) thick and is composed of up to six distinct salt units interbedded with gray shales and dolomite. The maximum aggregate thickness of salt approaches 275 meters (900 feet), but individual beds are not known to exceed a thickness of 120 meters (400 feet).

Structural control is not often recognized on the surface of the Appalachian Basin except near the boundaries. Some local anticlinal folds and related faults occur in the south, but it is uncertain if these structures extend downward as far as the Silurian salts. More commonly, the basin presents a pancake-type stratigraphy composed of both contiguous and inter-fingered layers gently dipping and thickening to the south.

Hydrology

Water used in the Appalachian Basin area is derived primarily from surface sources including rainfall, streams, lakes, and reservoirs. The annual rainfall in the basin commonly exceeds 100 centimeters (40 inches) and is sufficient to maintain several regional rivers and local streams. In addition to the surface water, some ground water is obtained from local shallow wells within the glacial sands and gravels. The water contained in the glacial drift aquifers is believed to interact with deeper Paleozoic water as a single hydrostratigraphic unit. The deeper Paleozoic rocks have low porosity and permeability values and contain only small quantities of ground water. The salinity of the water generally increases with depth and the Pleistocene/Paleozoic contact has been described as the fresh/saline water interface. However, near the fringes of the basin where the glacial drift is thinner, fresh water is obtained from Paleozoic aquifers and where the drift is thickest, saline waters are found in the lower Pleistocene deposits.

The deep aquifers, including those within the Salina Formation, contain partially to totally saturated brines with minor amounts of methane gas, and oil. The Silurian salts are known to have water bearing strata above and below them, however, the normally "tight" nature of these aquifers limits both the quantity of water and its potential to migrate. Additionally, the thick beds of impermeable shales, anhydrites, and salts provide an effective barrier to vertical movement. It seems reasonable that most short-term potential (less than 100 years) for fluid migration lies in changes induced artificially by drilling, pumping, or injection within the deep Paleozoic aquifers. Moderate to long-term migration (hundreds to thousands of years) is conceivable however, and both artificial and natural processes may act to determine its rate, direction, and carrying capacity.

Seismicity

The Appalachian Basin includes both low and moderate seismic risk areas. The southern portion of the basin bordering the Appalachian Structural Front is historically more active than the northern portion. Salt mines are located in the central area near the boundary of the low and moderate seismic regions. The long history of underground mining in this area, plus the tectonically stable setting, both infer that future seismicity will be minimal.

Michigan Basin

The Michigan and Appalachian Basins are often considered as one contiguous basin due to their similar stratigraphy. Structurally, the basins are separated by the Findley-Algonquin arches which together represent a stable basement ridge that remained high during deposition and depression of the major sedimentary basins on either side.

Stratigraphy and Structure

The Michigan Basin is described as a roughly circular structural depression bounded by the Canadian Shield on the north, the Cincinnati-Findley-Algonquin arches from the southeast to the northeast, and the Kankekee and Wisconsin arches on the southwest and west. This large sedimentary basin is centered near the Saginaw Bay area of Lake Huron where it attains a maximum stratigraphic thickness of nearly 3,665 meters (14,000 feet). The bedded deposits include sandstones, carbonates, evaporites, and shales of Cambrian, Ordovician, Silurian, and Devonian ages, overlain by variable thicknesses of unconsolidated Pleistocene glacial drift. The Paleozoic strata normally dip at less than one degree toward the center of the basin. The glacial sediments average about 75 meters (250 feet) thick, but locally extend down to 305 meters (1,000 feet).

The Silurian strata deposited in the Michigan Basin includes the Niagaran Series made up of the Cataract, Clinton, Lockport-Guelph, and Salina Groups and the Bass Island Formation. The Cataract Group is largely carbonates and shales with minor sandstone. It is approximately 60 meters (200 feet) thick in the Detroit area. The Clinton group is composed of shales, carbonates, and thin sandstone, but probably does not extend into the Detroit area since it pinches out from the northeast to the southwest. The Lockport-Guelph Group is composed largely of carbonates including dolomitic limestone, dolostone, and cherty limestone. The thickness of the Lockport-Guelph ranges between 30 and 120 meters (100 and 400 feet) in southeastern Michigan.

The Salina Group is composed of seven individual members designated A through G, from oldest to youngest. These units include carbonates, halite, anhydrite, and dolomitic shale. The A Unit has been further divided into two sub-units each composed of a carbonate/evaporite pair and designated A-1 and A-2.

The B Unit is predominately salt with thin interbedded anhydrite and dolostone. In the Detroit area of southeastern Michigan the B Unit is encountered at a depth of 340 meters (1,120 feet) and is conventionally mined at 345 meters (1,140 feet). Throughout much of the Michigan Basin the B Unit salt is found to be fairly uniform having an average thickness of 75 to 85 meters (240 to 275 feet). Approaching the perimeter of the basin the B Unit thins appreciably, occurring as noncontinuous lenses or not at all.

The C Unit is composed of gray/green dolomitic to sandy shale. The D Unit is largely salt beds separated by thin dolostone deposits. The

E Unit is a carbonate deposit which separates the D salts from the overlying F salt Unit. The F Unit includes up to six distinct salt beds separated by shales and shaly dolostones. The F salts attain a maximum thickness of nearly 365 meters (1,200 feet) in the central area of the Michigan Basin. The top Salina Unit is the G Unit composed of dense dolostone and argillaceous dolostone. It is sometimes considered a part of the overlying Bass Island's dolostone which is the uppermost Silurian formation in the Michigan Basin.

The lower Devonian deposits include the Garden Island and Bois Blanc Formations composed of interbedded limestones, dolomites, chert, and cherty limestones. A maximum thickness of 365 meters (1,200 feet) for the Garden Island and Bois Blanc Formations is known in the Michigan Basin although only a 40 meter (125 foot) thickness exists in the Detroit area.

The Middle Devonian includes the Detroit River Group made up of the Amherstburg sandstone and carbonates and the Lucas evaporites (salt and anhydrite). A thickness of approximately 115 meters (385 feet) for this group is found in the Detroit area, but its maximum thickness ranges up to 520 meters (1,700 feet) in parts of the Michigan Basin. The Dundee limestone and shale is above the Detroit River Group and ranges from 20 meters (65 feet) thick in the Detroit area to a maximum thickness of 135 meters (450 feet) in the central basin. In the Detroit area of southeastern Michigan, the Dundee is the topmost Paleozoic formation and is overlain by approximately 25 meters (75 feet) of glacial sand and clay. In other areas of the Michigan Basin additional Devonian, Mississippian, Pennsylvanian, and Jurassic deposits are known to occur.

The Michigan Basin, like the Appalachian Basin, is characterized by sparse structural expression at the surface. Local structures within the regional autogeosyncline are predominately broad anticlinal folds which trend to the northwest. These are occasionally associated with small displacement, high-angle, normal faults. It is probable that faulting of this type is more prevalent than available evidence indicates, but surface expression is masked by glacial drift.

In southeastern Michigan two fault systems associated with anticlinal folding have been described. The first is related to the Howell Anticline which trends N 50°W from the northwest corner of Wayne County across Livingston County. The second extends north into Michigan from Lucas County, Ohio along the Lenawee-Monroe Anticline. Both structures have related high-angle normal fault zones parallel to their long axes.

Hydrology

A majority of the fresh water used in the Michigan Basin is derived from rainfall that averages approximately 100 cm (40 inches) per year and surface sources including the Great Lakes. Shallow wells in glacial sand and gravel, and surface springs account for the remaining fresh water resources of the area.

Subsurface aquifers are plentiful in the glacial sand and gravel deposits with fairly large volumes and a high recharge rate being common. Contamination of the ground water increases with depth, and water below the Pleistocene/bedrock contact is normally saline.

Impermeable shale and salt beds form natural hydraulic barriers separating individual water-bearing formations within the thick Paleozoic sequence. Local permeability (transmissibility) between isolated aquifers depends in large part on the amount of drilling activity, since many deep drill holes penetrate the basin.

Permeable, water-bearing strata are known to exist above, below, and within the Silurian salts over wide areas of the Michigan Basin. Natural migration of deep ground water is believed to be minimal; however, local variations may exist. Migration due to drilling, injection, and solution mining of salt probably occurs on a local basis.

Seismicity--

The Michigan Basin is in a region of low seismic activity and has existed as a stable deposition basin for a long period of geologic time. Except along local fault zones, the possibility of extreme seismic activity is remote.

Permian Basin

The northern portion of the Permian salt basin underlies parts of southwest Colorado, most of southwestern Kansas, northwestern Oklahoma, the Texas Panhandle, and extreme northeastern New Mexico. The southern portion underlies much of southeast New Mexico and West Texas. The total combined area is approximately 193,080 sq kilometers (120,000 square miles). Separating the basin into northern and southern portions is largely arbitrary, based on conventional mining locations and the geological age differences of the mined deposits.

Northern--

The northern Permian Basin contains the Lower Permian Sumner group which includes the Hutchinson salt Member of the Wellington Formation. Depth of burial of the salt deposit ranges from greater than 455 meters (1,500 feet) in the west to about 120 meters (400 feet) in the east. The beds generally dip to the west at a very low angle. The thickness of the salt deposits is locally variable, but generally increases to the south. The salt in west-central Kansas is approximately 90 meters (300 feet) thick, while the salt in south-central Kansas often exceeds 215 meters (700 feet) in thickness. The purity of the salt deposits generally decreases as the thickness increases, and mining operations are limited to the purer beds in central Kansas.

Stratigraphy— The generalized stratigraphy of the Kansas Permian Basin includes sedimentary strata ranging from Cambrian to Tertiary geologic age, and greater than 1,830 meters (6,000 feet) in thickness.

Cambrian and Ordovician rocks overlie a metamorphic and igneous basement complex composed of gneisses, schists, quartzites, and granite plus other related rock types. The sedimentary sequence above the basement is predominately dolomite with some limestone and sandstone. The aggregate thickness of this sedimentary sequence approaches 455 meters (1,500 feet), but is locally variable.

Unconformably above the Cambrian - Ordovician strata are limestones and dolomites of Devonian and Silurian age. These rocks are of limited distribution with most occurrences in deep structural basins in northeastern and south-central Kansas.

Overlying the Silurian - Devonian strata are limestones of Mississippian age. Occasionally a lower shale unit underlies this predominately limestone sequence. The Mississippian strata have a maximum thickness of some 305 meters (1,000 feet), but are often thinner and separated from both the underlying and overlying strata by prominant unconformaties.

Pennsylvanian - Permian strata constitute a thick structural unit underlying all but the southeastern portion of Kansas. The aggregate thickness of these strata increases from negligible in the southeast to over 1,830 meters (6,000 feet) in the southwest. The Pennsylvanian deposits consist primarily of alternating layers of shale and limestone with minor lenticular sandstone deposits and a few coal beds. The thickness of the Pennsylvanian strata ranges from less than 305 meters (1,000 feet) to more than three times this thickness in some areas.

The Permian strata, which contain the bedded salt deposits, are typically very thick in western Kansas and outcrop in east-central Kansas. The lowest Permian rocks are primarily of marine origin and include shales and limestones similar to the underlying Pennsylvanian strata. The Early Permian strata are composed largely of red beds and evaporites that were probably deposited in a shallow marine basin. The main salt horizons are associated with the Blaine, Stone Corral, and Wellington formations with the conventionally mined beds occurring in the Hutchinson Salt Member of the Wellington Formation.

The Mesozoic rocks are predominately Cretaceous in age and unconformably overlie the Paleozoic strata westward from central Kansas. The greatest thickness occurs in northwest Kansas where nearly 915 meters (3,000 feet) of Cretaceous sandstones, clayey shales, and chalky limestones have been penetrated during drilling operations. Older Triassic and Jurassic deposits locally underlie the Cretaceous in southwestern Kansas. The Triassic sediments include red beds similar to the underlying Permian strata, while the Jurassic sediments include shale, sandstone, and limestone.

Tertiary deposits are fairly widespread in Kansas with the thickest deposits being confined to the western part of the state. These partly consolidated limestones, sandstones, and shales underlie unconsolidated Quaternary alluvium, loess, and dune sand.

The Lower Permian salt-bearing deposits lie in a broad synclinal trough trending to the northwest. These deposits are typically thicker on the limbs of the buried syncline, except where locally deposited over structural highs associated with the Precambrian basement. Figure 7 shows the generalized structure of Kansas. The Permian strata outcrop along a belt trending roughly north - south across east-central Kansas. A thickness of approximately 915 meters (3,000 feet) of Permian strata is exposed. However, the salt beds, subject to relatively rapid dissolution, only extend to within 120 meters (400 feet) of the surface.

The greatest dissolution of the Permian Basin salts in Kansas occurs underground along the eastern outcrop zone where the salt is retreating to the west at a rate estimated to be 10 kilometers (6 miles) every million years. In the west, the salt is overlain by as much as 455 meters (1,500 feet) of younger strata and dissolution is less active along this boundary and other deep margins to the north and south. The high salinity of rivers and streams crossing the basin is probably indicative of dissolution occurring in thin, noncontiguous salt beds interspersed above the major salt deposits.

Hydrology-- The Kansas Permian Basin underlies the extensive Great Plains physiographic Province. The surface is typically flat, or mildy undulating, and drainage is generally to the southeast. Major drainage channels include the Arkansas, Saline and Smokey Hill rivers in western and central Kansas. The latter two rivers originate in western Kansas from ground water discharge and intermittent rainfall. The annual precipitation for this area is approximately 50 to 75 centimeters (20 to 30 inches), with wide variation from year to year being common.

Potable ground water is confined to the first few hundred feet of the sediments, while aquifers in the deeper strata contain only brines. The shallower aquifers are not generally contiguous and show considerable variation in quantity, quality, recharge capacity, and depth of occurrence. Many of these shallow aquifers are tapped locally for domestic, livestock, and irrigation uses. In some areas, fresh water from shallow aquifers has migrated downward via old wells, resulting in dissolution of intersected salt deposits and subsequent surface settlement.

The deeper aquifers occur in interbedded sandstone and carbonate deposits below the Quaternary and unconsolidated Cretaceous units. The

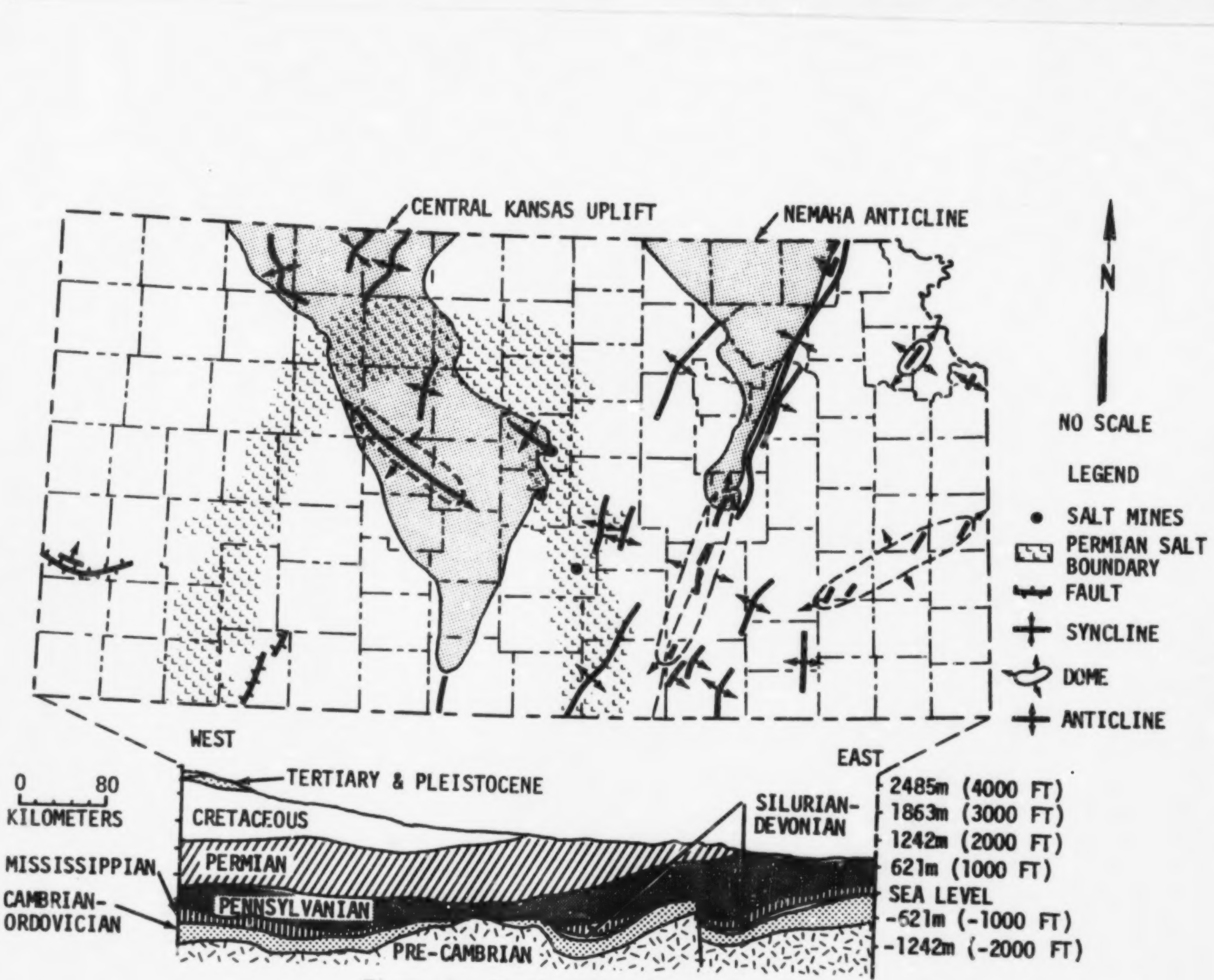

CENTRAL KANSAS UPLIFT
NEMAHA ANTICLINE
N
NO SCALE
LEGEND
SALT MINES
PERMIAN SALT BOUNDARY
FAULT
SYNCLINE
DOME
ANTICLINE
WEST
EAST
0
80
KILOMETERS
TERTIARY & PLEISTOCENE
CRETACEOUS
PERMIAN
MISSISSIPPIAN
CAMBRIAN-ORDOVICIAN
PENNSYLVANIAN
PRE-CAMBRIAN
SILURIAN-DEVONIAN
2485m (4000 FT)
1863m (3000 FT)
1242m (2000 FT)
621m (1000 FT)
SEA LEVEL
-621m (-1000 FT)
-1242m (-2000 FT)

Figure 7. Northern Permian Basin - Kansas.

high salinity of many local springs may indicate that both the shallow and deep aquifers behave as a single hydrostatic unit in many areas. On a regional basis, the deeper aquifers are typically isolated from one another by thick impermeable shale and salt deposits. The greatest potential for vertical transmissibility lies in artificially induced passages such as boreholes. Many of the deeper aquifers are known to have naturally high confinement pressure which has caused upward flow, sometimes of considerable height, in drill holes.

The Hutchinson salt bed is known to be isolated from overlying and underlying aquifers by very thick impermeable shales. The thorough studies performed for the Atomic Energy Commission concluded that potential water problems could be created by local commercial activities such as drilling, solution and conventional mining, fluid injection, etc. The possibility of leaching the salt bed naturally along faults, or by surface erosion, dissolution, or fracturing induced by increased overburden and crustal deformation of advancing glaciers, is remote.

Seismicity-- The Permian Basin lies in the stable mid-continent region of the United States. The thick stratified sediments appear to have been little disturbed since Precambrian time. Deposition has been controlled by gradual rising and falling of structural areas (isostatic adjustment) and deep seated faults or intrusions by igneous rocks are rarely encountered. The typically flat undisturbed bedding, plus the low incidence of historic seismicity, is suggestive of quiescence and stability over long periods of geologic time.

Southern--

The southern Permian Basin underlies parts of southeastern New Mexico and western Texas. The thick Permian salt beds extend over approximately 93,290 square kilometers (36,000 square miles) from Floyd County, Texas in the north to Pecos County, Texas in the south and from Mitchell County, Texas in the east to Eddy County, New Mexico in the west. The broad, shallow salt basin is superimposed over three parallel basement structures probably originating in Precambrian time. Figure 8 shows the major structural features of this basin.

On the west is the deep Delaware Basin, a structural trough extending some 200 kilometers (125 miles) to the southeast from Carlsbad, New Mexico. In general, the bedded deposits in the Delaware Basin dip gently to the east from their outcrop zone in the Guadalupe Mountains. Approximately 80 to 120 kilometers (50 to 75 miles) east of the western boundary there is a truncated fault zone trending along the west flank of the Central Basin Platform. The deepest parts of the Delaware Basin are found just to the west of this sharply uplifted plateau, and the total thickness of the sedimentary strata may exceed 7,620 meters (25,000 feet) in this area.

The elongated Central Basin Platform probably remained high during most of Paleozoic time as evidenced by relatively thin overlying strata,

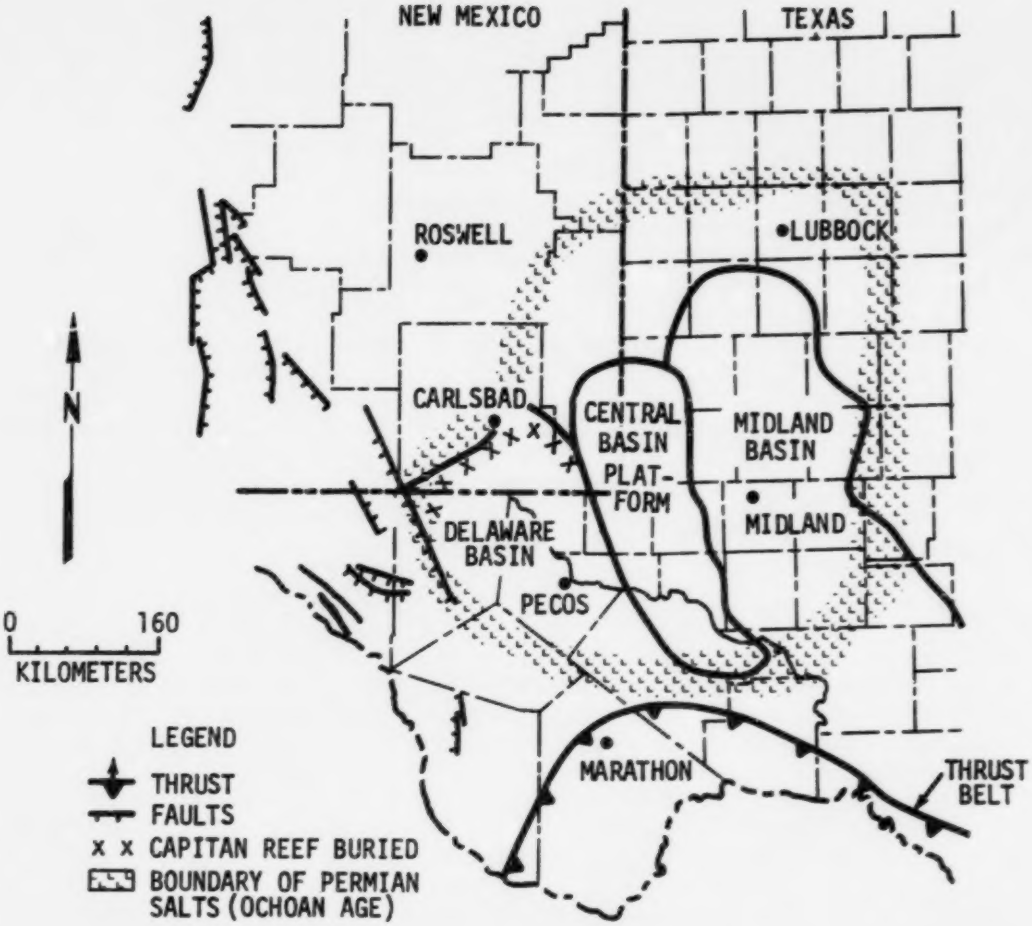

NEW MEXICO
TEXAS
ROSWELL
LUBBOCK
N
CARLSBAD
CENTRAL BASIN PLATFORM
MIDLAND BASIN
MIDLAND
DELAWARE BASIN
PECOS
0
160
KILOMETERS
MARATHON
THRUST BELT
LEGEND
THRUST
FAULTS
x x CAPITAN REEF BURIED
BOUNDARY OF PERMIAN SALTS (OCHOAN AGE)

Figure 8. Southern Permian Basin.

plus several missing intervals within the stratigraphic sequence. The Central Basin Platform is about 80 kilometers (50 miles) wide and 200 kilometers (125 miles) long.

On the east side and parallel to the Central Basin Platform is the broad Midland Basin depositional trough. It extends from near Lubbock Texas, some 320 kilometers (200 miles) to the southeast, and is typically about 95 kilometers (60 miles) wide. The Paleozoic strata are well represented, but their total thickness is not as great as in the Delaware Basin to the west. The strata dip gently toward the center of the trough from the east and west. The aggregate thickness of sediments laid down in the Midland Basin exceeds 3,960 meters (13,000 feet). Little structural control is evident except along the faulted boundary of the central platform.

Overlying most of the eastern half of the Delaware Basin, and nearly all of the Central Basin Platform and Midland Basin, plus overlapping a shelf area to the north and east of these basins, are thick Permian deposits including the Late Permian evaporites. The Late Permian beds form a very gentle synclinal trough trending to the northeast and underlying much of western Texas and southeast New Mexico.

The northern Delaware Basin and adjacent shelf area is of primary importance due to the occurrence of economic potash deposits. Regional control of these deposits was due primarily to extensive Permian reefs developed on the central Basin Platform and the massive Capitan Reef crossing the northern end of the Delaware Basin. The Capitan Reef structure probably acted to entrap seawater during periods when the sea retreated southward, thus forming local evaporation basins where the potash deposits were precipitated. The depositional sequence was cyclic and of long duration during much of Permian time.

Stratigraphy-- The Permian System includes the Wolfcamp and Leonard series of Lower Permian age, the Guadalupe (Capitan Reef) of Lower to Upper Permian age, and the Ochoa of Upper Permian age. The primary evaporite deposits occur in the Upper Permian Ochoa Series which includes an extensive lower salt-bearing sequence in the Castile, Salado, and Rustler formations, and a thin upper sequence in the Dewey Lake red beds. The aggregate thickness of the salt-bearing deposits exceeds 1,220 meters (4,000 feet) with up to 855 meters (2,800 feet) of salt in southeastern New Mexico. Over much of the Permian Basin, particularly on the higher shelf areas bordering the deep Delaware and Midland troughs, the salts range up from 0 to 185 meters (600 feet) thick.

The Castile Formation includes interbedded gray anhydrite and gray/brown limestone plus thick salt beds concentrated near the middle of the formation. The Castile pinches out to the north of the Delaware Basin, but thickens to over 455 meters (1,500 feet) to the south as it enters the depositional trough.

The Salado Formation overlies the Castile and is the main salt-bearing formation in the area. The Salado Formation is composed of interbedded rock salt including thin anhydrite and polyhalite units, occasional thick sandstone and siltstone beds, and thin seams of claystone underlying the evaporite units. Approximately 305 meters (1,000 feet) of Salado Formation is present on the north edge of the Delaware Basin with its thickness increasing southward and decreasing to the north.

The Salado Formation has been further subdivided (informally) into the lower salt member, the middle potassium rich zone (McNutt potash zone), and the upper salt member. Sylvite and related potassium and magnesium evaporites having economic importance are found in the middle member.

The Rustler Formation overlies the Salado Formation and is the uppermost salt formation of the Ochoan Series. In the northern Delaware Basin area it ranges in thickness from less than 60 meters (200 feet) in the north to greater than 120 meters (400 feet) to the south. The salt generally occurs as discontinuous local beds within the predominately anhydrite formation.

In the mining areas of the Delaware Basin, roughly 50 kilometers (30 miles) northeast of Carlsbad, there is up to 170 meters (550 feet) of reddish-brown siltstone and fine grained sandstone overlying the Rustler Formation. Collectively these deposits are known as the Dewey Lake Redbeds and are considered the topmost unit of the Ochoan Series.

The depth to salt varies locally, but in general the salts are shallower toward the perimeter of the Permian Basin. The change in depth is gradual to the north and east in the shelf and Midland Basin areas, but is more pronounced to the west and south and elsewhere along the boundary of the deep Delaware Basin. The commercial potash areas of New Mexico are on the northern margin of the Delaware Basin with mining operations both north and south of the buried Capitan Reef. The depth to commercial salt and potash formations in this area is between 200 meters (660 feet) and 535 meters (1,760 feet).

Overlying the Paleozoic rocks are undifferentiated Triassic rocks including yellow-brown conglomeritic sandstone, sandstone, siltstone and shale. The thickness is locally variable, but from 0 to 455 meters (1,500 feet) are known in southeast New Mexico.

Above the Triassic sediments are unconformable Cenozoic (Pliocene) gravels and sands, often cemented with caliche, known as the Ogallala Formation. A caliche "caprock" of cemented sandy limestone is also common in this region and it ranges up to 60 meters (200 feet) thick.

Hydrology-- The Pecos River and its local tributaries provide the major surface drainage across the Permian Basin of southeastern New Mexico. Runoff is derived from both meteoric and artesian sources with a substantial portion of the water originating northwest and northeast of the river basin area. Ground water recharge occurs in the Guadalupe Mountains to the west and in the river and stream channels to the northwest and northeast.

Fresh water is limited to the upper less-consolidated sediments (Ogallala and Quaternary deposits). All ground water becomes increasingly saline with depth, and along the western margin near-surface salts are being slowly removed by dissolution. Deeper water bearing strata are known to overlie the Salado Formation as aquifers in the Triassic deposits and the Rustler Formation. The Triassic sandstones, the Late Permian dolomites (Rustler Formation), and a basal conglomerate of the Rustler Formation yield water to wells and springs. The conglomeritic base of the Rustler is sometimes referred to as the "brine aquifer" and it is believed to contribute significantly to the dissolution of the upper Salado salts.

All of the aquifers above the Salado Formation appear to behave as a single hydrostatic unit over most of the basin area. A fairly uniform potentiometric surface, plus several dissolution features on the surface (sink holes and other subsidence features), are indicative of the intraformational movement of ground water above the salt. The ground water above the commercial potash deposits migrates to the south and southwest discharging into the Pecos River.

The Salado Formation salts are typically nonporous and impermeable, but they do contain small isolated brine and gas pockets.

Rocks underlying the thick Salado Formation are known to contain artesian brines, commonly under high hydrostatic pressure. Most of the known Paleozoic aquifers lie in the Capitan limestone and associated rocks. In the potash mining area these aquifers are deeply buried, as they are in much of the southeast New Mexico and West Texas basin area.

Dissolution of salt along the western edge of the basin has resulted in eastward migration at a rate estimated to be 10 to 13 kilometers (6 to 8 miles) per million years. At this rate, the evaporite deposits presently being mined for potash are assured a future existence of at least several million years. Changes in such controlling factors as diastrophism and meteorological conditions could speedup or slowdown the removal process.

Seismicity-- Like the northern area of the Permian Basin, the land in the southern area has been very stable. The low-angle bedding and low topographic relief indicate little tectonic change over a long geologic period. The last major diastrophic movement probably occurred at the end of Paleozoic time. However, gradual changes have since occurred as depression of the basins and uplift of the plateaus. Additionally, the eastward rotation (downward) of the Delaware Basin along the western margin of the Central Basin Platform probably continued into Mesozoic and Cenozoic time. There is no evidence to indicate a change from the relatively stable conditions which have long dominated the region.

Gulf Coast Embayment

All of the salt mined in the Gulf Coast region is believed to originate from the Louann Salt bed which was probably deposited during early Jurassic time. The Louann salt has widespread distribution in the Gulf Coast Region, however most of the bedded sequence is well below 1,220 meters (4,000 feet) in depth. The salt which is commercially available occurs as diapiric domes that have formed in response to the extreme overburden pressure on the thick, deeply buried bedded salt. Of the 263 known or suspected onshore salt domes, only 7 are presently being mined using conventional methods. Two of these mines are in Texas and five are in Louisiana.

It has been postulated that the interior domes have essentially stabilized since Miocene time, while the coastal domes are still undergoing some degree of diapiric intrusion. Geologic and hydrologic data are deficient in many respects despite extensive oil and gas exploration in the region, thus evidence supporting suspected geological features is often sparse.

Stratigraphy--

The Gulf Coast Embayment includes an immense stratigraphic sequence of Late Paleozoic to recent sediments. Paleozoic shale and slate have been intersected by drill holes near the interior margins of the basin; but toward the central and southern areas, older strata, if present, are deeply buried under thick Mesozoic and Cenozoic sediments. Generally speaking, the broad depositional basin is composed of thick interbedded carbonates, evaporites, and clastics of marine and terrestrial origin. These post-Paleozoic deposits range from outcrop zones on the interior perimeter of the embayment to an aggregate thickness estimated to exceed 15,240 meters (50,000 feet) near the coastal regions.

Two salt horizons are known from drilling operations. The upper salt bed occurs in the Buckner formation of Jurassic age and ranges from 0 to 40 meters (130 feet) thick at depths from 915 to 3,050 meters (3,000 to 10,000 feet). The second salt bed, and what is believed to be the "mother" salt for the salt domes, is the Louann salt of Early Jurassic (?) age. The Louann salt appears to be highly variable in thickness, ranging from less than 30 meters (100 feet) to more than 915 meters (3,000 feet) in drill holes. These extremes might represent thicker and thinner lenses within an undulating, plastic formation.

Paleozoic aged rocks outcrop in the folded mountainous zones bordering the Gulf Coast Embayment on the northwest and northeast, and have been penetrated by drill holes inside the basin perimeter. Except for the peripheral occurrences of Paleozoic shale and slate, little information about the nature of the rocks underlying the Mesozoic and Cenozoic strata is presently available due to their extreme depth.

The Eagle Mills formation of Early Jurassic (?) age unconformably overlies the Late Paleozoic rocks, and it is composed of red shale, sandstone, anhydrite, and the thick Louann salt. Near the perimeter of the embayment in southern Arkansas, the Eagle Mills formation is unconformably overlain by Late Cretaceous and Tertiary sediments; but increasingly older sequences of Jurassic and Cretaceous strata overlie the formation further to the south.

Structure--

The huge regional structure described as the Gulf Coast Embayment underlies East Texas, southern Arkansas, Mississippi, Alabama, and Louisiana. The gently sloping continental basin deepens toward the coast where it enters the Gulf Coast Geosyncline which forms the Gulf of Mexico. The Ouchita Tectonic Belt, a zone of folded strata extending from southern Arkansas south across east central Texas is the western boundary of the embayment. The Ouchita folding continues from southeast Arkansas across Louisiana into Mississippi, forming the north and east boundary of the salt dome basin. A synclinal extension of the embayment structure, without domal salt, continues north along the Mississippi River to extreme southern Illinois. The southern or coastal area of the continental structure forms the depositional rim of the Gulf Coast Geosyncline.

The Gulf Coast Embayment structure contains several significant structural features related to salt dome occurrences. The salt domes which occur in the Interior Subprovince are primarily located in three deep synclinal basins separated by structural uplifts. From the northwest to the northeast these structures are the East Texas Syncline, the Sabine Uplift, the North Louisiana Syncline, the Monroe Uplift, and the broad Mississippi Dome Basin. Each of these synclinal basins contains salt domes, and collectively, the area is known as the Interior Dome Subprovince. Figure 9 shows the major structural features of the Gulf Coast Embayment.

The other major subprovince lies closer to the coast and is not known to be controlled by large deep-seated tectonic structures. Many local anticlines and synclines do occur, and they are commonly associated with the diapiric salt. Several of the coastal domes appear to be rooted in common anticlinal fold structures at depth, and this type structure may be essential to the formation of salt domes. The other most prevalent structures found in the Gulf Coast area are widespread slump faults which typically trend parallel to the coast. These too may be related to dome formation, but a common relationship is not yet established.

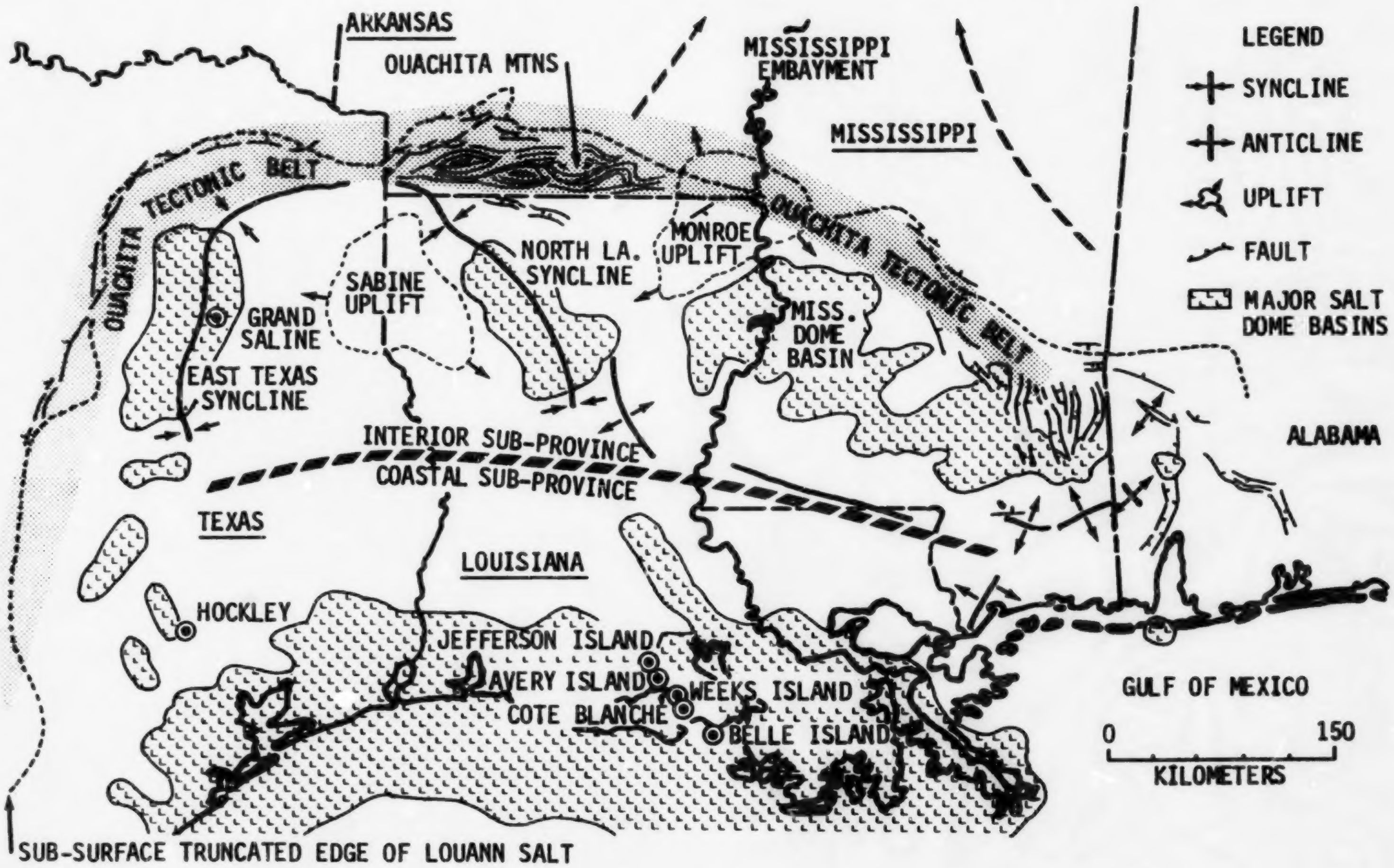

ARKANSAS
OUACHITA MTNS
MISSISSIPPI EMBAYMENT
MISSISSIPPI
LEGEND
SYNCLINE
ANTICLINE
UPLIFT
FAULT
MAJOR SALT DOME BASINS
OUACHITA TECTONIC BELT
MONROE UPLIFT
NORTH LA. SYNCLINE
SABINE UPLIFT
GRAND SALINE
EAST TEXAS SYNCLINE
MISS. DOME BASIN
OUACHITA TECTONIC BELT
ALABAMA
INTERIOR SUB-PROVINCE
COASTAL SUB-PROVINCE
TEXAS
LOUISIANA
HOCKLEY
JEFFERSON ISLAND
AVERY ISLAND
WEEKS ISLAND
COTE BLANCHE
BELLE ISLAND
GULF OF MEXICO
0
150
KILOMETERS
SUB-SURFACE TRUNCATED EDGE OF LOUANN SALT

Figure 9. Gulf Coast Embayment.

The formation of the Gulf Coast Geosyncline showing the growth and genesis of salt domes has been graphically illustrated by Hanna using a sequence of four cross sections each representing a different stage of development, Figure 10. Although highly idealized, Hanna's model provides a plausible explanation for the interior and coastal occurrences of domal salt.

Recent laboratory studies have indicated that large scale, short-term (geologically) flow of salt will be initiated upon reaching certain minimum conditions. Given a sufficient thickness and distribution of salt, an overburden pressure of 82,735 kilonewtons per square meter (12,000 psi) and a temperature of 200 degrees centigrade can initiate vertical flow. Once flow is started, the lower density salt tends to continually feed the column until the source is depleted. The salt plug will then end its upward migration when its bulk density is equal to the density of the surrounding strata. Since these figures are the result of idealized modeling, they probably represent only part of the diapiric mechanism. The extreme depth of burial of the Louann Salt near the coast makes it difficult to obtain information about the basement structure and deep stratigraphy which might influence diapiric movement.

The physical dimensions of the salt domes are quite variable. The diameter of the domes range up to several kilometers (miles) and many are elongated in one direction. In vertical section, the shapes range from straight to variously inclined walls with rounded, flat, and mushroom tops. A few of the younger coastal domes intrude to the surface while many others are found much deeper. It is possible that many of the near surface coastal domes may have risen more than 13,715 meters (45,000 feet) from their source. The interior basin domes originated from a shallower depth 4,570 meters (15,000 feet) and commonly extend to within 305 meters (1,000 feet) of the surface.

The purity of diapiric salt appears to reflect the vertical distance it has intruded. In general, the older interior domes migrated vertically less than half the distance of the coastal domes. The interior domes are typically 92 to 96 percent halite, while the coastal domes range from 95 to 99 percent halite. This difference in purity has been ascribed to some type of natural refining during intrusion, however, the actual process is yet to be explained.

Many shallow salt domes are capped with single or multiple layers of anhydrite, gypsum, and limestone. Field and laboratory studies point to caprock formation resulting from salt dissolution and subsequent concentration of the insoluble constituents carried within a salt diapir. Since this mechanism would seem to be self-limiting, it does not explain the cap rock thicknesses encountered, nor does it explain the differential separation (layering) of the multiple lithology caprocks.

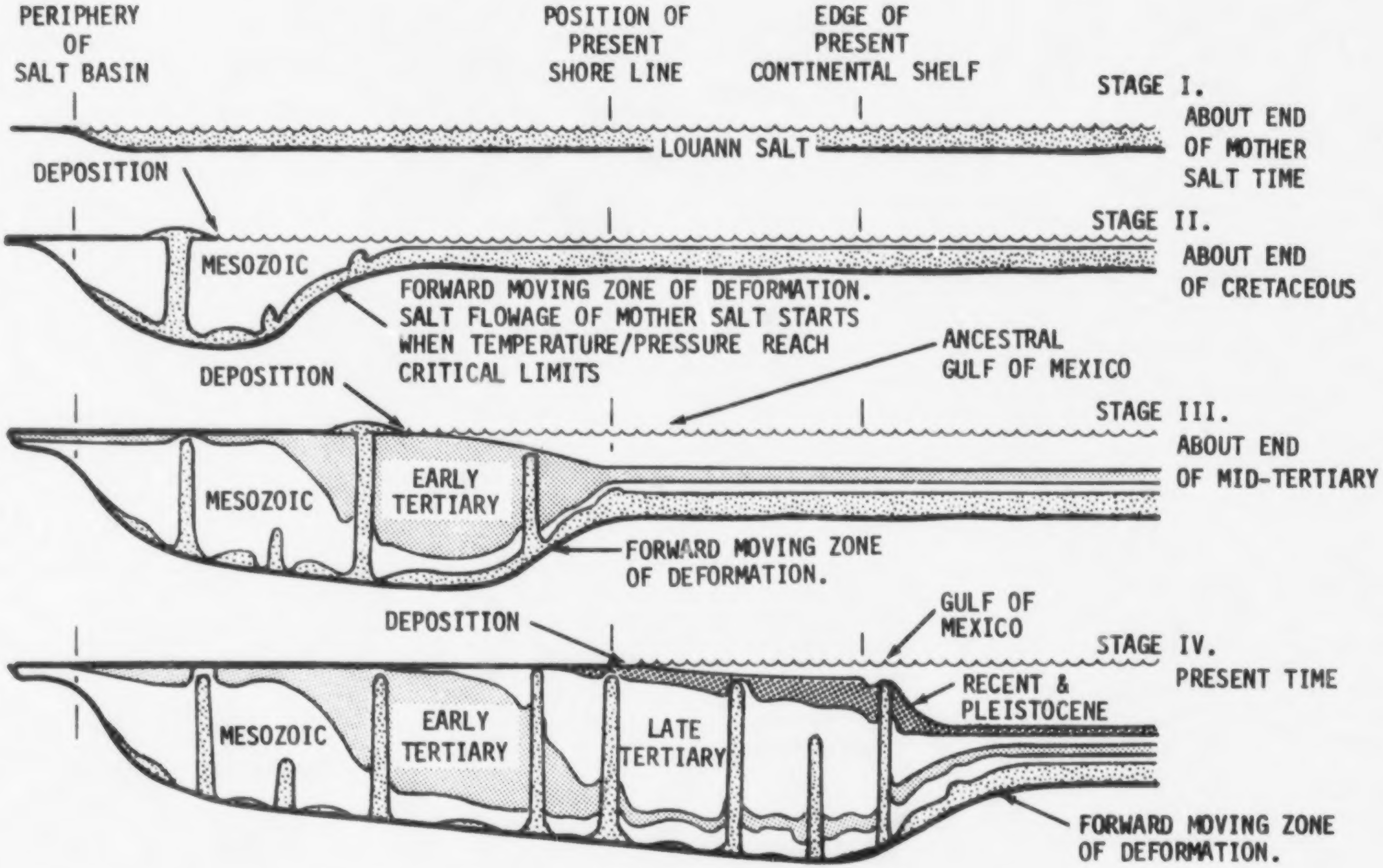

PERIPHERY OF SALT BASIN
POSITION OF PRESENT SHORE LINE
EDGE OF PRESENT CONTINENTAL SHELF
STAGE I.
ABOUT END OF MOTHER SALT TIME
LOUANN SALT
DEPOSITION
STAGE II.
ABOUT END OF CRETACEOUS
MESOZOIC
FORWARD MOVING ZONE OF DEFORMATION. SALT FLOWAGE OF MOTHER SALT STARTS WHEN TEMPERATURE/PRESSURE REACH CRITICAL LIMITS
ANCESTRAL GULF OF MEXICO
DEPOSITION
STAGE III.
ABOUT END OF MID-TERTIARY
MESOZOIC
EARLY TERTIARY
FORWARD MOVING ZONE OF DEFORMATION.
DEPOSITION
GULF OF MEXICO
STAGE IV.
PRESENT TIME
RECENT & PLEISTOCENE
MESOZOIC
EARLY TERTIARY
LATE TERTIARY
FORWARD MOVING ZONE OF DEFORMATION.

Figure 10. Evolution of Gulf Coast Salt Domes.

Hydrology--

The Gulf Coast Embayment is a large hydrologic basin in which both surface and subsurface water drains generally southward toward the Gulf of Mexico. The exceptionally thick sequence of strata, including several highly permeable units, allow large volumes of ground water to migrate and/or be contained in subsurface aquifers.

The recharge areas are in outcrop zones along the northern perimeter and along the many major rivers crossing the region. Rainfall throughout the recharge zone is in excess of 100 centimeters (40 inches) annually, and much of this amount undoubtedly finds its way into the permeable, southerly dipping strata. Wherever the strata have been dislocated by faulting or salt dome intrusion, ground water rises to the surface under natural hydrostatic pressure.

Nearly all of the salt domes are surrounded by water saturated strata, often extending to very great depths and typically quite permeable. The hydrologic setting of every salt dome is unique and in most cases, despite extensive drilling, information is sparse.

Many salt domes are expressed on the surface as depressed basins which often contain standing water. In addition, the overlying sediments and/or certain units in the caprock, are porous, permeable, and saturated and this has often caused problems when sinking mine shafts.

The primary water problem in salt dome mines has historically centered on water leakage around the shaft openings. In a few cases, the resulting dissolution has caused the loss of entire mines when uncontrolled flooding occurred.

Other major water problems encountered in salt domes result from large lenses of water-bearing sandstone which occasionally occur as inclusions within the salt. These miniature reservoirs have been known to discharge significant amounts of water under pressure when encountered in mines. Finally, the potential for rapid flooding is inherent in the confined area of any salt dome surrounded by permeable saturated strata. Penetration of the impervious dome wall, by whatever means, can provide an entry for water, thus the need for excellent control when mining near the perimeter often exists.

A long range water problem which might affect a large portion of the present Gulf Coast area is related to a change in sea level. If the present polar ice undergoes appreciable melting, the subsequent rise of sea level would inundate much of the Gulf Coast Region. The potential for such a sea level change is probably not significant for short-term storage operations, but might pose a potential hazard hundreds or thousands of years from now.

Seismicity--

The Gulf Coast region is characterized by low seismic activity during the historic past. Two areas of the basin, one in eastern Texas and the other along the coast of southern Mississippi, are in no-damage zones of the Seismic Risk Map of the United States. The remaining area of the Gulf Coast Embayment is in a zone of low seismic risk.

Local and regional tectonic features are normally attributed to rapid sediment deposition and salt intrusion, and consist of slump faults and graben structures. The seaward migration of the depositional basin has resulted in zones of down faulting on the landward side. These slump fault systems typically trend east-west parallel to the regional strike. The salt diapirs commonly exhibit local faulting radiating away from the domes.

Historically the Gulf Coast Embayment is very stable, while geologically the area has apparently undergone no major diastrophic change during a long period of deposition. This implies that the seismicity of the region has probably been low, and should remain low for a long time to come.

OTHER ENVIRONMENTS

Other lithologic environments including gypsum, potash, shale, limestone, and granite are briefly described on the following pages.

Gypsum

Gypsum, like salt, is an evaporite mineral deposited during periods of ocean retreat when basin catchments held and concentrated saline water by evaporation. Over a long period of time, the increasingly concentrated minerals fell out of solution, forming the large evaporite deposits.

Gypsum is commonly associated with the other evaporite minerals and occurs as very pure discreet beds or mixed with anhydrite. Economic deposits occur within the evaporite sequences of the major sedimentary basins and in the cap rock formations over many salt domes.

The major value of gypsum is derived from its use as plaster and in the manufacture of wallboard. It can be described as a large volume, low value product requiring high purity and easy access to be profitably exploited. Due to a combination of its economics and mode of occurrence, most gypsum is mined by open-pit methods. The few underground room and pillar mines which do exist are typically less than 90 meters (300 feet) deep; however, they often include a large volume of mined space.

As a waste storage medium, gypsum is in some respects superior to other rock types. It is essentially impervious to water, insoluble, deforms plastically, and is generally nonreactive. In addition, it is widely distributed and easily excavated, and is often associated with other impermeable rock sequences.

On the negative side, present mining operations do not lend themselves to waste storage. The commonly shallow workings are likely to have water problems unless located in arid regions. Near-surface deposits are often interbedded with carbonate and shale deposits due to dissolution or decay of other less resistent evaporites. Roof and floor control of the underground openings is usually maintained in proximity to these adjacent sedimentary rocks, and consequently the size of opening is limited and the potential for roof falls along shale partings is increased.

In summary, gypsum is an excellent rock medium for hazardous waste storage. However, the use of current mining operations are questionable for this purpose due to stability problems and shallow depths. Deeper mines, engineered for stability, could be excellent waste repositories.

Potash

Potash is produced from several mines in southeastern New Mexico. The important economic occurrences are within the thick Permian salt deposits as relatively thin discrete beds. The high concentration of potassium salts (potash) is a consequence of unique climatic and salinity conditions resulting in increased precipitation of these salts. Additional concentration by replacement and redeposition may also have occurred.

The potash bearing beds extend over thousands of square kilometers, but are not contiguous over large areas. The deposits are interbedded through more than a hundred meters (1,000 feet) of vertical depth, and most mines operate from depths of 215 to 520 meters (700 to 1,700 feet).

Halite and potash salts are so similar that properties of salt can, for all practical purposes, be taken to include potash. The physical characteristics, including plasticity, strength, structure, permeability and solubility are essentially the same.

Potash has a higher economic value than halite, and this is reflected in the mining methods employed. Room and pillar designs are commonly used; however, the extraction ratios are high, approaching 90 percent. This high ratio is achieved by methodically "robbing" the pillars so that the roof collapses under controlled conditions. The obvious result of this mining method is that the remaining space is limited to haulageways.

On the basis of geologic properties, potash appears to be a good storage medium for hazardous chemical wastes, but present mining methods result in a limited volume of underground space being available.

Shale

Shale is a rock medium in which mined openings for the emplacement of hazardous wastes could be constructed. The desirable criteria of shale are its very low permeability, high ion exchange capacity, moderate plasticity, and wide distribution.

Shale is a laminated sedimentary rock in which the constituent particles are predominantly clay size. The average composition of shale is 59 percent clay minerals, 20 percent quartz and chert, 8 percent feldspar, 7 percent carbonates, 3 percent iron oxides, 1 percent organic material, and 2 percent other. The common clay minerals in shale are illite, chlorite mica, montmorillonite, and kaolinite. The very low permeability of shales would minimize the movement of ground water into or out of underground openings. The average porosity of shale is about 13 percent. In areas of intense deformation of the strata, secondary permeability resulting from fractures would be higher than the original shale permeability and should be avoided.

The greatest potential benefit of storage in shales is the high ion exchange capacity of these rocks, which may neutralize waste toxicity or otherwise limit their migration from the area of emplacement. The relatively high plasticity of most shales will also tend to prevent the movement of waste material from an emplacement site because of its natural tendency to close minor openings.

Shales are very widely distributed in the earth's crust. Sedimentary rocks underlie about 75 percent of the total land area of the earth and approximately 42 to 56 percent of the sedimentary rocks are shales. Figure 11 indicates those areas of the United States that are underlain by thick bodies of shale. Table 1 lists and identifies the important shale deposits of the United States.

The difficulties of constructing underground openings in shale are increased by the tendency of the rock to separate along bedding planes, and the inclusion of swelling clays such as montmorillonite. Montmorillonite is abundant in the Mesozoic and Cenozoic sedimentary rocks of the United States but rare in the pre-Mesozoic rocks. However, relatively stable openings can be constructed in shale as shown by the existence of several underground caverns that have been mined for the storage of liquid petroleum products in shale deposits.

Thick sequences of shale in areas of minor or no seismic risk, and suitable for underground storage facility construction, occur in many parts of the United States. Occasional variations in sedimentation sometimes result in interbedded sandstone or limestone units to produce

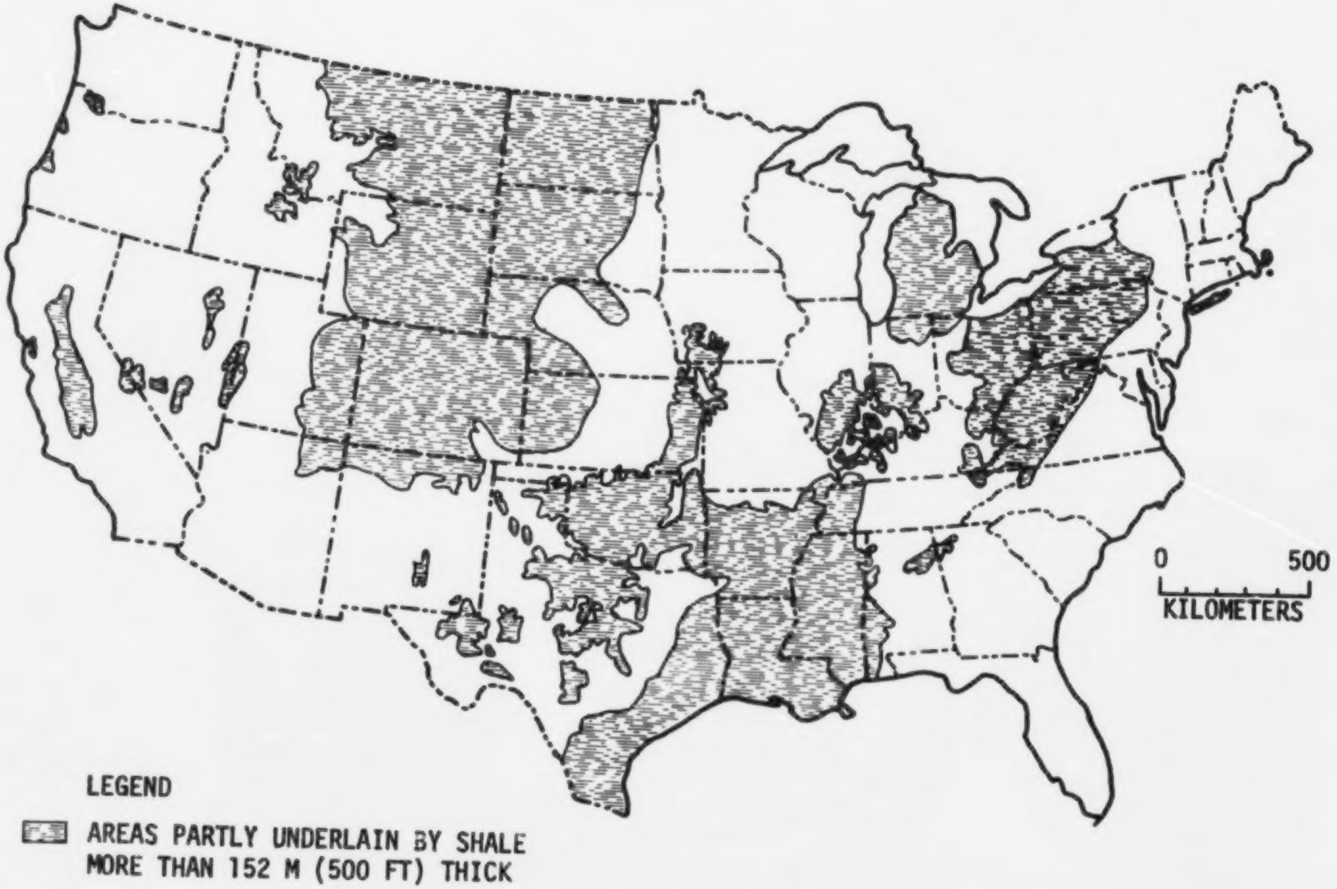

0 500
KILOMETERS
LEGEND
▨ AREAS PARTLY UNDERLAIN BY SHALE MORE THAN 152 M (500 FT) THICK

Figure 11. Thick Shale Deposits in the United States.

Table 1. SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Pacific Mountain System				
Oligocene sh.*	More than 10,000	Claystone and siltstone	Slightly tuffaceous			2-3	Locally abundant
Eocene Moody Sh. Mbr., Toledo Fm.	1,500-1,800	Mudstone and sandstone	Tuffaceous, montmorillonitic	Low	Abundant fractures	2	
Miocene Nye Mudstone	2,500	Mudstone and siltstone	Montmorillonitic	Moderate	Moderately abundant fractures	2	Sparse
Eocene-Oligocene Bastendorff Sh.	2,300	Shale and sandstone	Tuffaceous, montmorillonitic			1	Sparse
Eocene Capay Fm.	300-2,500	Brown to gray shale; local sandstone at base				2-3	Locally abundant
Jurassic Knoxville Fm.	As much as 10,000	Shale and siltstone local sandstone and conglomerate		Low	Abundant fractures	2-3	Locally abundant
Cretaceous Shasta Series	About 10,000	Mudstone and siltstone; less sandstone and conglomerate				2-3	Locally abundant
Paleocene Martinez Fm.	As much as 2,000	Claystone and sandstone; local conglomerate	Silty			2-3	Locally abundant
Cretaceous-Paleocene Moreno Fm.	About 2,000 average	Brown and gray shale; local sandstone	Partly siliceous, partly calcareous			2-3	Locally abundant

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Pacific Mountain System				
Eocene Lodo Fm.	As much as 5,000	Siltstone and claystone; less sandstone				2-3	Locally abundant
Oligocene Tumey Sh.	As much as 1,500	Basal sandstone (800 ft), shale (700 ft)				2-3	Locally abundant
Eocene Kreyenhagen Sh.	600-4,000	Claystone, siltstone, shale, diatomite; less sandstone	Diatomaccous and gypsiferous shale			2-3	Locally abundant
Miocene sh.	100-1,000 (buried)	Mudstone and sandstone	Silty, sandy			2-3	Locally abundant
			Intermontane Plateaus				
Devonian-Mississippian Pilot Sh.	As much as 1,200	Shale, limestone, and siltstone	Calcareous	Low	Abundant fractures	2-3	Sparse
Mississippian Doughnut Fm.	As much as 500	Shale and limestone				1-2	
Mississippian Chainman Fm.	As much as 5,000	Shale, sandstone, and limestone		Low	Abundant fractures	2-3	Sparse
Cretaceous Mancos Sh.	0-5,000	Shale, siltstone, and sandstone	Montmorillonitic	Moderate to high	Sparse fractures	1-2	Locally abundant
Paleocene Nacimiento Fm.	400-800	Claystone and mudstone		Moderate to high	Sparse fractures	1-2	Locally abundant
Pennsylvanian Panther Seep Fm.	800-2,400	Shale, sandstone, and limestone	Silty and carbonaceous	Low		1-2	

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Rocky Mountain System				
Cretaceous Bearpaw Sh.	As much as 1,200	Shale, siltstone, sandstone, and bentonite	Montmorillonitic	Moderate to high	Sparse fractures	1	Locally abundant
Mississippian-Pennsylvanian Big Snowy Fm.	As much as 500	Shale, sandstone, and limestone	Calcareous	Low	Moderately abundant fractures	1-2	Locally abundant
Cambrian Wolsey Sh.	As much as 1,000	Shale, sandstone, and limestone		Low	Moderately abundant to abundant fractures	1-2-3	Locally abundant
Cambrian Park Sh.	As much as 600	Shale		Low	Moderately abundant to abundant fractures	1-2	Locally abundant
Mississippian Milligen Fm.	More than 5,500	Shale and limestone	Calcareous and carbonaceous	Low	Abundant fractures	2-3	Sparse
Cretaceous Pierre Sh.	Less than 500 to more than 5,000	Claystone, shale, mudstone, and bentonite	Montmorillonitic	Moderate to high	Sparse fractures	1	Locally abundant
Pennsylvanian sh.*	As much as 2,000	Shale		Low	Moderately abundant fractures	1	

** ESSA/Coast and Geodetic Survey, 1969
0 - no seismic risk
1 - minor seismic risk
2 - moderate seismic risk
3 - major seismic risk
(See figure   of this report for outline of seismic areas in U.S.)

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Interior Plains				
Devonian-Mississippian Ellsworth Sh.	As much as 600	Shale and siltstone		Low to moder-ate	Sparse to moderately abundant fractures	1	Locally abundant
Mississippian Coldwater Sh.	About 500 to more	Shale, siltstone, sandstone, limestone and dolomite	Silty and calcareous	Low to moderate	Sparse to moderately abundant fractures	1	Locally abundant
Pennsylvanian Des Moines Series	Locally more than 500	Shale, limestone, sandstone, and coal	Partly carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2	Locally abundant
Mississippian Borden Gp.	As much as about 760	Siltstone, shale, and sandstone	Silty	Low to moderate	Moderately abundant fractures	1-2-3	Locally abundant
Pennsylvanian Melansboro Gp.	Locally more than 500	Shale, sandstone, limestone, and coal	Partly carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2-3	Locally abundant
Pennsylvanian Kewanee Gp.	Locally more than 500	Shale, sandstone, limestone, and coal	Partly carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2-3	Locally abundant
Pennsylvania Virgil Series	Locally more than 500	Shale and limestone		Low to moderate	Sparse to moderately abundant fractures	1-2	Locally abundant

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Interior Plains				
Mississippian-Pennsylvanian	Locally more than 4,000 (deeply buried)	Claystone, sandstone, ano limestone		Low to moderate	Locally abundant fractures	1-2	Locally abundant
Pennsylvanian Des Moines Series	Locally more than 2,300	Claystone, sandstone, limestone, and coal	Partly carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2	Locally abundant
Pennsylvanian Canyon and Cisco Gps.	Locally more than 500	Shale, limestone, sandstone, and coal		Low to moderate	Sparse to moderately abundant fractures	0-1	Locally abundant
Mississippian Barnett Sh.	Locally more than 500	Shale and limestone	Locally petroliferous	Low to moderate		0-1	Locally abundant
Pennsylvanian Smithwick Sh.	Locally more than 500	Shale, siltstone, and sandstone		Low to moderate	Moderately abundant fractures	0-1	Locally abundant
Pennsylvanian Atoka Fm.	Locally more than 5,000	Shale, siltstone, and sandstone	Slightly carbonaceous	Low to moderate	Moderately abundant to abundant fractures	1-2	Locally abundant
Pennsylvanian Bloyd Sh.	Locally more than 500	Shale and limestone		Low to moderate	Moderately abundant fractures	1	Locally abundant
Mississippian-Pennsylvanian Johns Valley Sh.	200-1,000	Shale, sandstone, and limestone	Scattered pebbles and boulders	Low to moderate	Moderately abundant to abundant fractures	1	Sparse

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Interior Plains				
Ordovician Mazarn Sh.	About 1,000	Shale, sandstone, and limestone. Veins of quartz and calcite		Low	Moderately abundant to abundant fractures	1	Sparse
Mississippian Stanley Sh.	6,000-12,000	Shale, siltstone, and sandstone	Locally siliceous	Low to moderate	Moderately abundant to abundant fractures	1	Sparse
			Atlantic Plain and Appalachian Highlands				
Devonian Ohio Sh.	Average about 1,100	Shale, siltstone, and limestone	Locally calcareous and carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2	Locally abundant
Ordovician Reedsville Sh.	About 830	Shale, siltstone, and limestone	Calcareous	Low to moderate	Moderately abundant fractures	1-2	Locally abundant
Ordovician Queensten Sh.	About 854	Shale	Partly silty and calcareous	Low to moderate		1-2	Locally abundant
Devonian Hamilton Gp.	About 900	Shale and limestone	Locally calcareous and carbonaceous	Low to moderate	Sparse to moderately abundant fractures	1-2	Locally abundant
Ordovician Utica, Frankfort, and Pulaski Fms.	About 1,200 (buried)	Shale and siltstone	Silty	Low to moderate	Moderately abundant fractures	1	Locally abundant

Table 1 (continued). SELECTED THICK BODIES OF SHALE IN THE CONTERMINOUS UNITED STATES

Age and stratigraphic name	Thickness (in feet)	Rock types	Minor constituents of rocks	Estimated plasticity	Estimated abundance of fractures	Regional seismicity (0-3)**	Abundance of drill holes or mines
			Atlantic Plain and Appalachian Highlands				
Ordovician Canajoharic Sh.	About 2,000	Shale, siltstone, and sandstone		Low to moderate	Moderately abundant fractures	1-2	Locally abundant
Ordovician Martinsburg Sh.	About 4,000-8,000	Shale, siltstone, and sandstone		Low	Abundant fractures	1	Sparse
Mississippian Hedges and Myers Sh.	About 970	Shale, sandstone, and coal	Partly carbonaceous and partly sandy	Low	Abundant fractures	1-2	Sparse
Paleocene Porters Creek Clay	As much as 600	Clay, sandstone, and limestone	Montmorillonitic	High	Sparse fractures	1-2-3	Locally abundant
Cretaceous Eagle Ford Sh.	Average about 475	Shale	Montmorillonitic	Moderate to high	Sparse fractures	0-1	Locally abundant
Mississippian Floyd Sh.	As much as 1,500	Shale, sandstone, and limestone		Low	Abundant fractures	1-2	
Miocene Hawthorn Fm.	As much as 500	Clay and sandstone	Partly sandy	High	Sparse fractures	1-2	Sparse

** ESSA/Coast and Geodetic Survey, 1969
0 - no seismic risk
1 - minor seismic risk
2 - moderate seismic risk
3 - major seismic risk
(See figure 3 of this report for outline of seismic areas in U.S.)

locally unacceptable permeability conditions within a generally favorable lithologic unit.

Limestone

Limestone can be considered as a potential storage medium due to its widespread occurrence and exploitation. Many limestone mines, including cement and lime, exist throughout the United States.

Limestone is subject to water dissolution in wet climates which results in many caverns, sinks, and open water channels. Therefore, in these areas its utility for mined storage may be severly limited. In arid regions, dissolution is less active although long-term changes in meteorologic conditions could alter this situation.

The physical characteristics of limestone rock often make it a favorable mined medium. Thick, massive, and widespread deposits are common in major sedimentary basins and provide very stable openings where not faulted or fractured. Water migration typically occurs along jointed, fractured, and faulted zones. Limestone is reactive to acid solutions and this may be a potential problem for its use as a waste storage medium.

The volume of mined space in limestone is enormous; however, many mines are relatively close to the surface. It seems probable however, that a few of these sites will be found suitable for waste storage.

Granite

Another rock medium in which mined space could be created for the storage of hazardous wastes is intrusive igneous rock such as granite. The major reasons that granite-type igneous rocks can be considered are their low permeabilities and high mechanical strength.

The permeability of granites is low due to the manner in which igneous rocks are formed. These rocks are formed by the cooling and solidification of a molten rock mass that invades the earth's crust, but does not reach the surface. Because of high confining pressures, very little void space is created in the rock as it solidifies, with the average porosity of a medium-grained granite being about 1.6 percent.

Secondary permeability resulting from fractures and joints can, however, be a significant problem in intrusive igneous rocks. The fractures and joints are a result of stresses created in the rock as it solidifies and from local tectonic forces. In some areas, ground water could enter the mine openings through the interconnected fractures and joints, but various sealing techniques can be used to control this type of water inflow.

The high mechanical strength of intrusive igneous rock facilitates the construction of very stable underground openings. Because of its low economic value and its many surface exposures, very few underground mined openings exist in granite, except in those areas where minerals associated with the intrusive body are concentrated. A few mined openings in granite have been constructed for the underground storage of liquefied petroleum products.

Figure 12 shows those areas of the United States in which intrusive igneous rocks can be found at or near surface. This figure does not show those intrusive igneous rocks that occur within Zone 3 of the Seismic Risk Map of the United States or would be indurated by a 150 meter (492 foot) rise in sea level.

OPERATING MINES

Each of the major conventional salt mines are described using information available in the literature. In most cases the published information was concerned with mining or construction problems with little regard for the geology except as it was pertinent to a problem.

Two limestone mines are also described. These were picked to illustrate the extremes of underground mining conditions in limestone. The last description is a generalized description of hard rock metal mines in sedimentary lithologies.

This broad overview provides a fair representation of these mining environments, while at the same time, it indicates the lack of pertinent geologic information about the mines.

Retsof Mine

The International Salt Company's Retsof Mine in Livingston County, New York, is the largest underground salt mine in the Western Hemisphere. Salt has been mined here since the completion of the first shaft in 1885. Salt has been produced in New York State since 1661 by the evaporation of brine from salt springs. In 1878, rock salt was found in the state when a well drilled in Wyoming County by the Vacuum Oil Company penetrated a 20 meter (70 foot) thick salt bed at a depth of 390 meters (1,270 feet). As a result of this discovery, salt was soon being mined by solution methods.

After drilling an exploratory hole to prove the existence of salt, the Retsof Mining Company began sinking a 3.7 by 5.5 meter (12 by 18 foot) shaft in August of 1884. The shaft was completed in the fall of 1885 and since then, the Retsof Mining Company has produced salt by room and pillar mining methods.

Since completion of a second 2.7 by 8.5 meter (9 by 20 foot) shaft in 1920, a panel system of room and pillar mining has been used. The

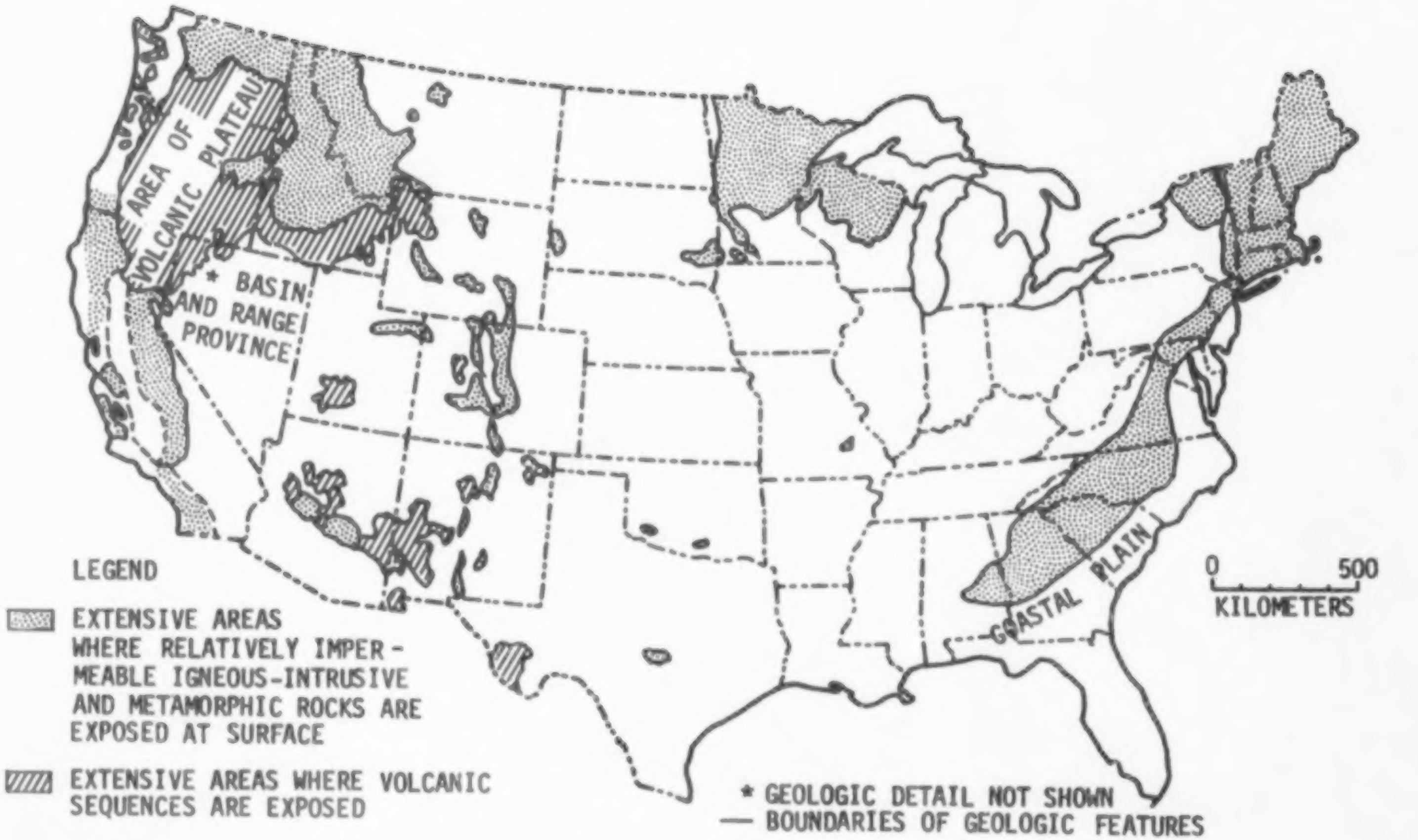

AREA OF VOLCANIC PLATEAU
* BASIN AND RANGE PROVINCE
COASTAL PLAIN
0
500
KILOMETERS
LEGEND
EXTENSIVE AREAS WHERE RELATIVELY IMPERMEABLE IGNEOUS-INTRUSIVE AND METAMORPHIC ROCKS ARE EXPOSED AT SURFACE
EXTENSIVE AREAS WHERE VOLCANIC SEQUENCES ARE EXPOSED
* GEOLOGIC DETAIL NOT SHOWN
— BOUNDARIES OF GEOLOGIC FEATURES

Figure 12. Distribution of Igneous Rock in the United States.

panels are 152.4 by 731.5 meters (500 by 2,400 feet) with 20 rooms to a panel. Seventy percent of the salt is extracted with the remaining thirty percent left as pillars to support the roof. During periods of peak demand, production can reach 4,540 metric tons (5,000 tons) per 8 hour shift. As of 1967, the estimated yearly production was 2,042,550 metric tons (2,250,000 tons). This is equivalent to about 935,000 cubic meters (33 million cubic feet) per year.

The salt bed mined at the Retsof Mine is one of several in the Syracuse Salt Formation of the Upper Silurian Salina Group. It is 2.7 to 3 meters (9 to 10 feet) thick. The mining level is 324 meters (1,063 feet) below the surface and 99.4 meters (326 feet) below sea level. Immediately above and below the mined salt are other less pure salt beds that contain shale layers. There is no mention in the literature of any folding or faulting in the immediate mine area. The dip of the bed is less than one percent to the south. Figure 13 shows a geologic column through the shaft. The crude rock salt in the salt zone is grayish-white in color and 96 to 98 percent sodium chloride in coarse, well-crystallized grains. The remaining 2 to 4 percent consists of magnesium chloride, calcium chloride, calcium sulfate, and water.

The mine workings are dry except for water that seeps down the shafts. Seepage down the shafts is about 1,325 liters (350 gallons) per hour. Pumping 20 to 25 hours per week, with a 190 liter (50 gallon) per minute capacity pump, can remove all the water that accumulates. The formations immediately above and below the mined salt bed do not produce any water. Exploratory drilling has revealed a brackish aquifer approximately 65.3 meters (280 feet) below the mined salt bed. Because of numerous intervening shale beds though, no fluid communication has been established except through man-made openings.

Although there is no report in the literature of stability problems in the Retsof Mine, roof falls and floor heaving often occurs in mines with high extraction rates.

The temperature in the mine remains nearly constant throughout the year at 16°C (61°F). The relative humidity averages 58 percent.

Examination of the Seismic Risk Map of the United States indicates that possible damage from an earthquake in the Retsof Mine would range from minor to moderate from earthquake intensities of V to VII on the Modified Mercalli Intensity Scale of 1931.

Seneca Lake Mine

Rock salt is also mined in New York State by the Morton Salt Company from its Seneca Lake Mine in Yates County. The salt bed being mined at Seneca Lake is one of several in the Silurian Salina Group. The bed is about 3.0 meters (10 feet) thick and approximately 610 meters (2,000 feet) below the surface. Production at the mine can reach 7,550 metric

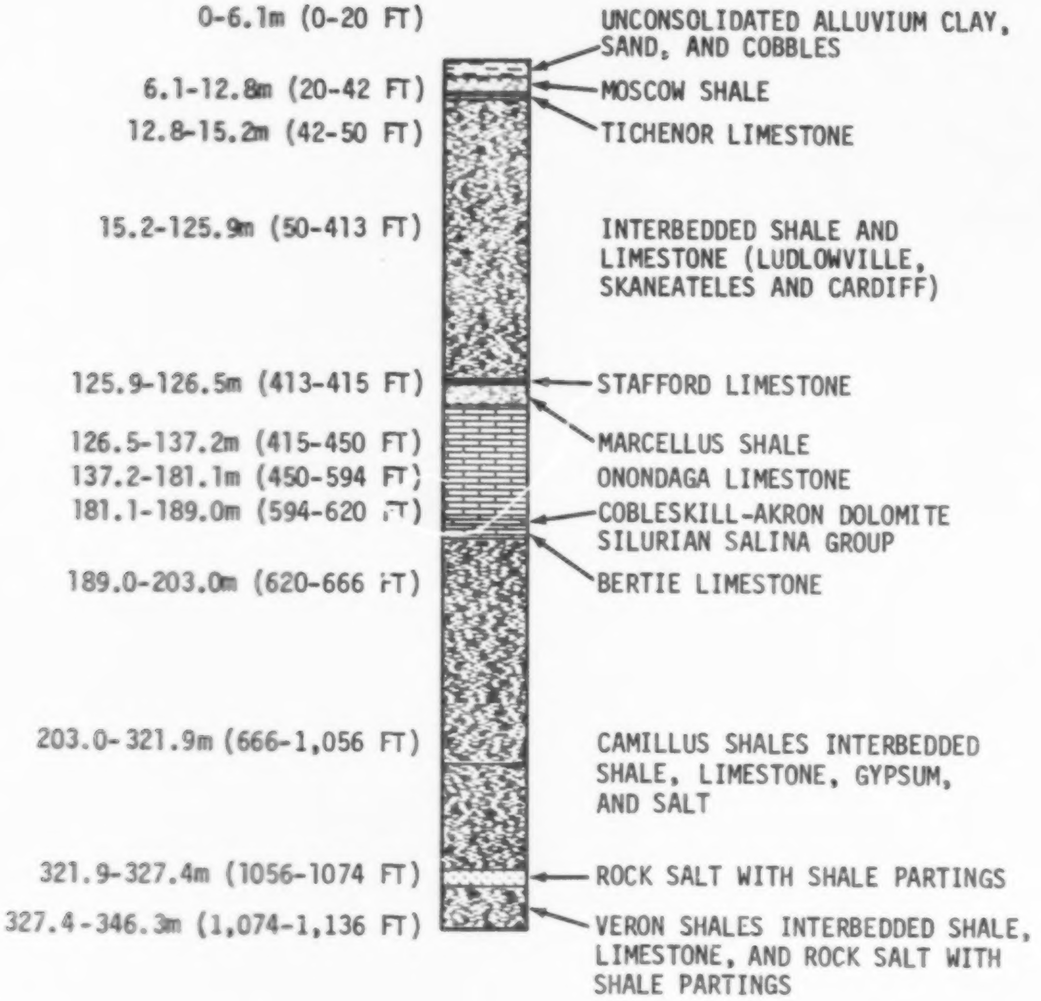

0-6.1m (0-20 FT)
6.1-12.8m (20-42 FT)
12.8-15.2m (42-50 FT)
15.2-125.9m (50-413 FT)
125.9-126.5m (413-415 FT)
126.5-137.2m (415-450 FT)
137.2-181.1m (450-594 FT)
181.1-189.0m (594-620 FT)
189.0-203.0m (620-666 FT)
203.0-321.9m (666-1,056 FT)
321.9-327.4m (1056-1074 FT)
327.4-346.3m (1,074-1,136 FT)
UNCONSOLIDATED ALLUVIUM CLAY, SAND, AND COBBLES
MOSCOW SHALE
TICHENOR LIMESTONE
INTERBEDDED SHALE AND LIMESTONE (LUDLOWVILLE, SKANEATELES AND CARDIFF)
STAFFORD LIMESTONE
MARCELLUS SHALE
ONONDAGA LIMESTONE
COBLESKILL-AKRON DOLOMITE
SILURIAN SALINA GROUP
BERTIE LIMESTONE
CAMILLUS SHALES INTERBEDDED SHALE, LIMESTONE, GYPSUM, AND SALT
ROCK SALT WITH SHALE PARTINGS
VERON SHALES INTERBEDDED SHALE, LIMESTONE, AND ROCK SALT WITH SHALE PARTINGS

Figure 13. Stratigraphic Column - Retsof Shaft.

tons (8,300 tons) per day which is equivalent to about 3,400 cubic meters (120,000 cubic feet) of mine volume.

It has been stated that there is no stability problem at the salt mine at Seneca Lake. The only water entering the mine workings is from seepage, about 19 liters (5 gallons) per minute, down the two access shafts.

Seismicity at the Seneca Lake Mine has not been severe during the historic past.

Cayuga Salt Mine

Cargill Incorporated mines salt near Ithica, New York. Production can reach 3,550 metric tons (3,900 tons) per day from a salt bed in the Silurian Salina Group. Local thickening and thinning of the salt bed is present at the Cargill Salt Mine.

It is reported that there are no problems with water entering the mine workings at the present time; however, water has in the past entered through the shaft when hydro-fracturing operations were underway at nearby brine wells.

The Cargill Mine is situated near the boundary of the 1 and 2 Seismic Risk Zones on the Seismic Risk Map of the United States, thus indicating a Modified Mercalli intensity of minor to moderate surface damage.

Fairport Harbor Mine

The Morton Salt Company produces salt by conventional mining at its Fairport Harbor Mine located in Grand River, Lake County, Ohio. Mining operations began in 1959 and the company now produces over 909,000 metric tons (one million tons) per year from the mine. This is equivalent to approximately 410,000 cubic meters (14.5 million cubic feet) of the mine volume.

The salt bed being mined by the Morton Salt Company is the second salt horizon of the Silurian Salina Group. This horizon is equivalent to the F-1 unit in the Michigan Basin. The mining level is 585.5 meters (1,921 feet) below the surface. No information has been found concerning mine stability or other mining problems at the Fairport Harbor Mine, but it is assumed that they would be about the same as problems encountered in other mines in bedded salt deposits.

The Fairport Harbor Mine is situated between the 1 and 2 Seismic Risk Zones on the Seismic Risk Map of the United States, indicating minor to moderate earthquake intensities during the historic past.

Whiskey Island Mine

The International Salt Company produces over 909,000 metric tons (one million tons) per year from its Whiskey Island Mine located under the Whiskey Island industrial district of Cleveland, Ohio. The working level is 539.5 meters (1,770 feet) below the surface with a large part of the workings extending under Lake Erie. Rock salt at the Whiskey Island Mine is produced from the first salt horizon of the Silurian Saline Group. The first salt horizon of Ohio is equivalent to the F-2 unit of the Michigan Basin.

Operations at the Whiskey Island Mine are unique in that it is the only salt mine in the United States that is intersected by faults. One of the faults intersecting the mine has a throw of 17.4 meters (57 feet). Special mining procedures are followed at the Whiskey Island Mine to avoid problems created by the faulting and extensive horizontal exploratory drilling is done to prevent mining into water filled fault spaces.

The Whiskey Island Mine is located in Seismic Risk Zone 1 on the Seismic Risk Map of the United States. This corresponds to modified Mercalli Intensities of V and VI, indicating minor surface damage.

Detroit Mine

Although about 25 percent of the United States production of salt is from the Michigan Basin, most of the salt mined in this basin is produced by solution mining. The International Salt Company's mine near Detroit is the only room and pillar salt mine in the basin.

The International Salt Company has mined salt from the B Unit of the Salina Formation since the completion of the first shaft in 1910. The salt bed is a comparatively flat 6.1 meter (20 foot) thick bed that is bordered on top and bottom by limestone beds. Figure 13 shows a geologic column through the shaft.

The mining level is 313.9 meters (1,030 feet) below the surface. Very little information on the size of the mine workings is available, but the production is about 2,700 metric tons (3,000 tons) per day. During construction of the shaft, four water-bearing intervals were penetrated before reaching the salt. The water flow from these intervals into the open shaft was estimated to be approximately 7.6 million liters (2 million gallons) per minute.

Examination of the Seismic Risk Map of the United States indicates that the International Salt Company's Detroit Mine is in Zone 1. Structures in Zone 1 of the Seismic Risk Map could sustain minor damage from distant earthquakes.

Kansas Salt Mines

The Hutchinson salt member of the Wellington Formation (Early Permian Age) is conventionally mined at three sites in central Kansas. Five

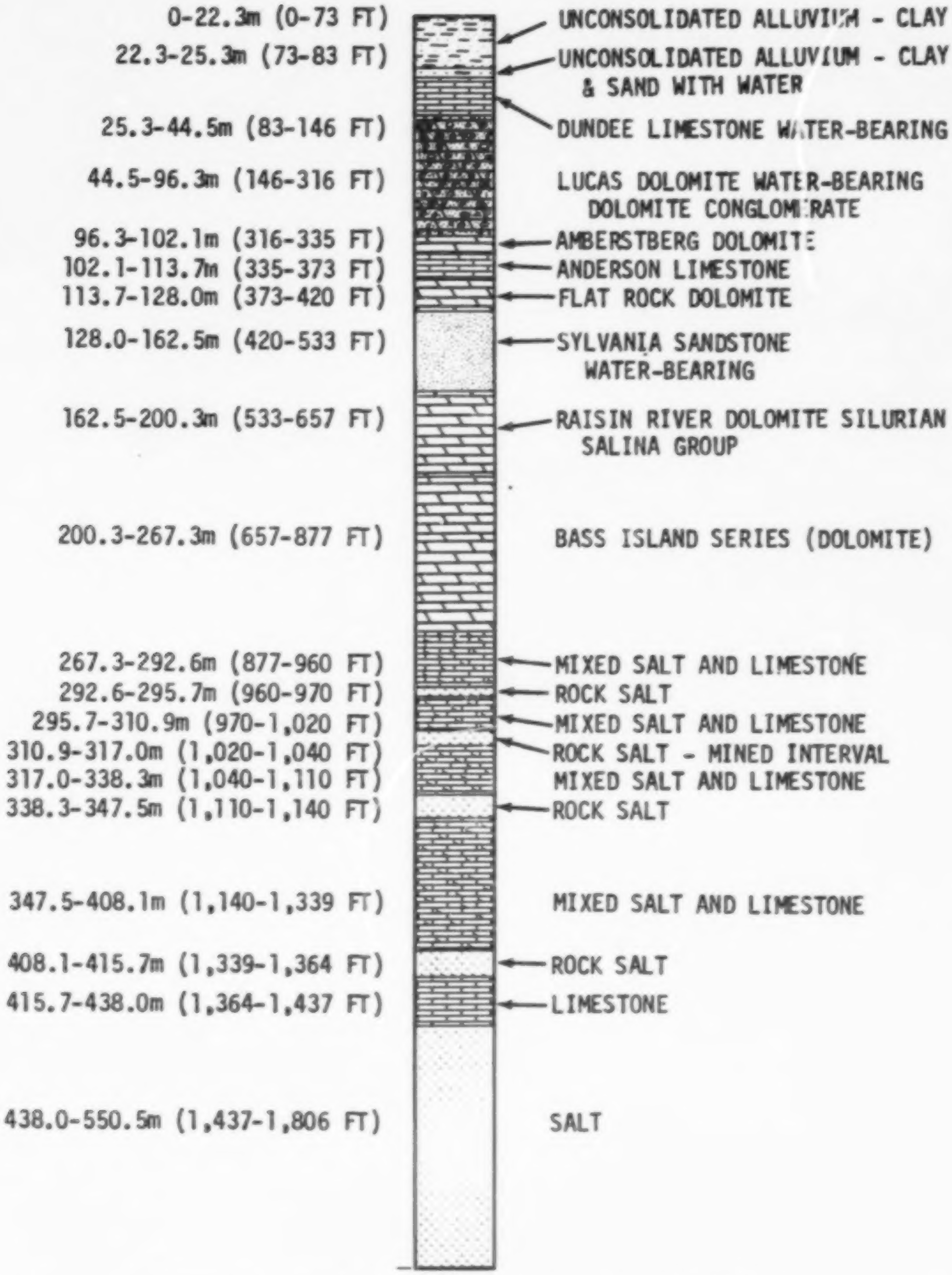

0-22.3m (0-73 FT)
UNCONSOLIDATED ALLUVIUM - CLAY
22.3-25.3m (73-83 FT)
UNCONSOLIDATED ALLUVIUM - CLAY & SAND WITH WATER
25.3-44.5m (83-146 FT)
DUNDEE LIMESTONE WATER-BEARING
44.5-96.3m (146-316 FT)
LUCAS DOLOMITE WATER-BEARING DOLOMITE CONGLOMERATE
96.3-102.1m (316-335 FT)
AMBERSTBERG DOLOMITE
102.1-113.7m (335-373 FT)
ANDERSON LIMESTONE
113.7-128.0m (373-420 FT)
FLAT ROCK DOLOMITE
128.0-162.5m (420-533 FT)
SYLVANIA SANDSTONE WATER-BEARING
162.5-200.3m (533-657 FT)
RAISIN RIVER DOLOMITE SILURIAN SALINA GROUP
200.3-267.3m (657-877 FT)
BASS ISLAND SERIES (DOLOMITE)
267.3-292.6m (877-960 FT)
MIXED SALT AND LIMESTONE
292.6-295.7m (960-970 FT)
ROCK SALT
295.7-310.9m (970-1,020 FT)
MIXED SALT AND LIMESTONE
310.9-317.0m (1,020-1,040 FT)
ROCK SALT - MINED INTERVAL
317.0-338.3m (1,040-1,110 FT)
MIXED SALT AND LIMESTONE
338.3-347.5m (1,110-1,140 FT)
ROCK SALT
347.5-408.1m (1,140-1,339 FT)
MIXED SALT AND LIMESTONE
408.1-415.7m (1,339-1,364 FT)
ROCK SALT
415.7-438.0m (1,364-1,437 FT)
LIMESTONE
438.0-550.5m (1,437-1,806 FT)
SALT

Figure 14. Stratigraphic Column - Detroit Shaft.

nonoperating mines are also located in this region, however two of these are known to be flooded, the status of two others is unknown, and one is nonoperating but in reasonably good condition. The nonoperating mine located at Lyons is owned by the Carey Salt Company and was most recently utilized as a model facility for radioactive waste storage.

The present mining activity in Kansas is at the Carey Salt Company mine in Hutchinson, the Independent Salt Company mine at Kanopolis, and the American Salt Company mine at Lyons.

Carey Mine--

The Carey mine at Hutchinson excavates salt at a depth of 196.6 meters from a 3 meter (10 foot) thick bed of high purity halite (95%). Removal is through a 4.6 meter (15 x 15 feet) square shaft. The estimated mine volume is in excess of 1.8 million cubic meters (100 million cubic feet).

The stability of the Carey mine is quite impressive with only occasional signs of deformation being visible. Weaker areas are routinely supported by wood pillars; however, these areas are not common and are usually attributable to excessive extraction ratios. Roof and floor control is maintained along continuous, parallel and nearly horizontal shale seams which are natural plains of parting and allow very uniform openings. The mine is dry and aquifers above and below the mine are well isolated by thick salt plus extensive overlying and underlying shale units.

The Carey mine is unique in that a portion of the older workings are utilized concurrently for the storage of valuable documents. A portion of the mine excavated some 50 years ago is leased to Underground Vaults and Storage Incorporated and is operated independently of the salt mine. The near constant temperature (20.6°C or 69°F) and relative humidity (50%) are almost ideal conditions for the storage of documents, film, and other similar material. A basic requirement for this operation to be successful is a safe, stable environment since many of the items stored are irreplaceable.

The Carey mine is not known to intersect any faults and is located in a tectonically stable region (Seismic Risk Zone 1).

Independent Salt Mine--

The Independent Salt Company mine in Ellsworth County, Kansas mines a 3 meter (10 foot) thick salt bed at a working depth of 263.7 meters (865 feet). The salt is removed through two shafts, one of which is 2.4 by 6.1 meters (8 by 20 feet) while the other is 2.4 by 4.9 meters (8 by 16 feet). It is estimated that approximately 7.1 million cubic meters (250 million cubic feet) of space has been excavated at the Independent mine.

Little information is available concerning the structural and hydrologic conditions of the Independent mine. However, they are expected to be similar to other salt mines, relating primarily to extraction ratios and engineering design. Flooding potential is remote due to the thickness of the salt and shale sequences which separate the aquifers from the mine opening. Seismic risk is low in the mine area, and historically the region has been tectonically quiet.

American Salt Mine--

The American Salt Company operation, located near Lyons, Kansas, produces salt by both conventional and solution mines. The conventional mine produces salt from a 2.6 meter (8.6 foot) thick bed of high purity salt at a depth of 302.7 meters (993 feet). Present production is through a 2.1 by 2.1 meter (7 by 7-foot) shaft. The volume of mined space is estimated to be about 2.9 million cubic meters (45 million cubic feet). The structural integrity of the conventional mine is typically very good except where the extraction has exceeded 75 percent.

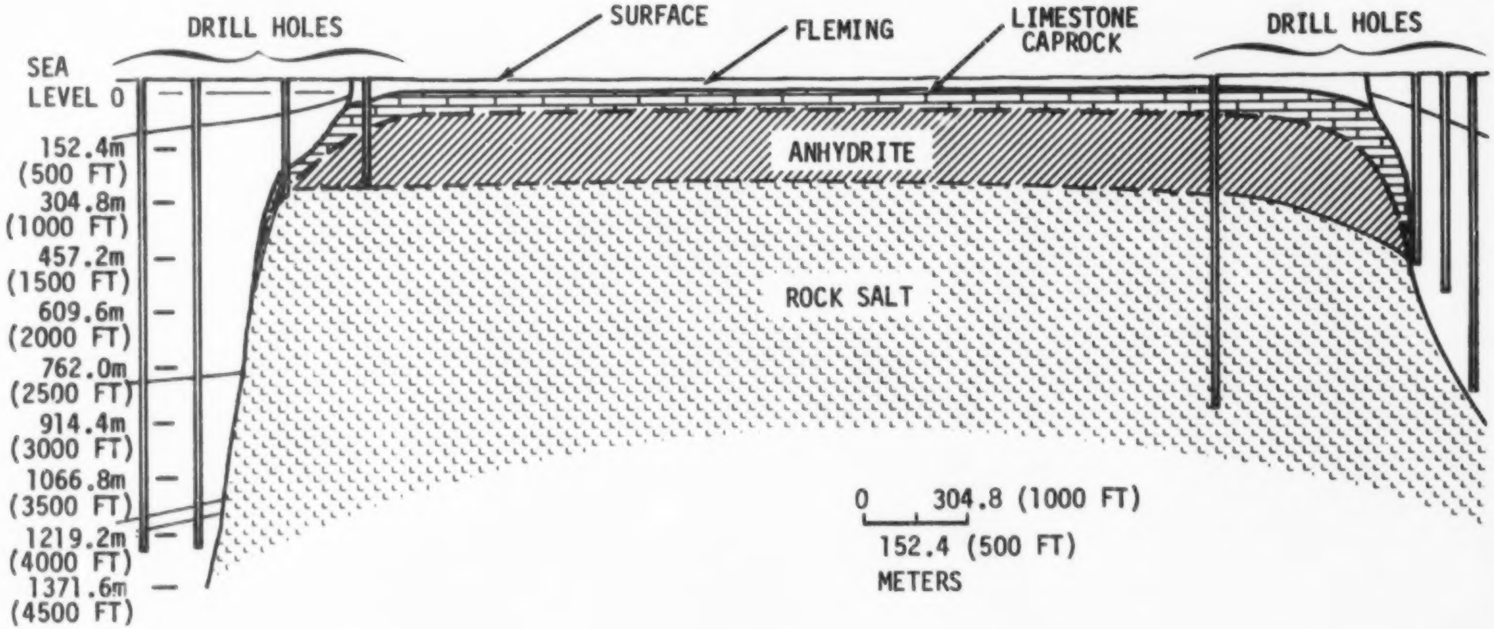
Hydrologic isolation is similar to the other Kansas salt mines except that there are many nearby boreholes. In one instance the mine intersected an unsurveyed and abandoned borehole which fortunately was plugged tight. Had the plug been ineffective, serious water inflows might have resulted. Other old boreholes in the Lyons area have been known to allow water inflows which have, in time, resulted in extensive salt dissolution and surface subsidence. In addition, the hydraulic mining operations near the American mine would seem to offer some low, but indeterminate risk to the conventional mine.

No faults are indicated in the American mine and seismicity is low in this region, rating a Zone 1 on the Seismic Risk Map.

Hockley Mine

The United Salt Corporation mines salt from the Hockley dome in Harris County, Texas. The mine site is approximately 50 kilometers (30 miles) northwest of Houston. The Hockley salt dome was discovered in 1906 when an exploratory hole was drilled to investigate surface occurrences of sulfur water and natural gas. During the years since this first hole was drilled, over one hundred additional wells have been sunk while exploring for petroleum, sulfur, and salt. Figure 15 shows an idealized cross section of the Hockley Dome. Salt has been conventionally mined at Hockley since the completion of the first shaft in 1932 at a depth of 464.8 meters (1,525 feet). For a time during World War II, gypsum was mined from the cap rock overlying Hockley dome and in 1945, a small oil field was developed.

Information concerning salt production at the Hockley Mine was not found in the literature. Mine design was simply noted as room and pillar. The present volume and utility of mined space is unknown, but



DRILL HOLES
SURFACE
FLEMING
LIMESTONE CAPROCK
DRILL HOLES
SEA LEVEL 0
152.4m (500 FT)
304.8m (1000 FT)
457.2m (1500 FT)
609.6m (2000 FT)
762.0m (2500 FT)
914.4m (3000 FT)
1066.8m (3500 FT)
1219.2m (4000 FT)
1371.6m (4500 FT)
ANHYDRITE
ROCK SALT
0
304.8 (1000 FT)
152.4 (500 FT)
METERS

Figure 15. Cross Section Hockley Dome.

is assumed to be quite large based on the number of years of operation, and the large volume economics of salt production.

Drill hole data indicates that the intrusive salt stock is oval shaped with its long axis trending north-south. The outside dimensions of the dome are roughly 5,182 meters by 3,962 meters (17,000 by 13,000 feet). The top of the salt is nearly flat ranging from 50.3 to 60.9 meters (165 to 200 feet) above sea level in the recorded drill holes.

Overlying the salt stock are Miocene and Oligocene sands and clays and a thick cap rock formation of brecciated calcite and limestone, gypsum, and massive anhydrite with local sandy zones. Figure 16 shows the stratigraphic column of the mine shaft.

The unconsolidated sand and clay deposits extend to a depth of 23.2 meters (76 feet) at the mine shaft and locally contain water. The upper cap rock unit is a brecciated limestone extensively interlaced with vuggy stringers and veins of calcite. The unit contains a bottom layer of less than 1 meter (30 inches) composed of gray calcitic sand. The 9 meter (30 foot) thick limestone unit is very porous and yielded both oil and water during construction of the shaft. A gypsum unit underlies the limestone and extends down 5.5 meters (18 feet) where it grades into the thick anhydrite below.

The anhydrite unit is 270 meters (886 feet) thick. Between 243.8 and 274.3 meters (800 and 900 feet) in depth, there exist many thin calcareous sandstone bands interbedded with the anhydrite as well as larger sandstone inclusions. The sandstone beds are typically less than 5 centimeters (2 inches) thick while the larger rounded inclusions reach 10 centimeters (4 inches) in diameter. Near the base of the anhydrite unit, occasional isolated salt lenses were encountered ranging up to 3 meters (10 feet) long by 1.5 meters (5 feet) wide by 25 centimeters (10 inches) thick.

The structure of the anhydrite is generally massive with a well developed, near horizontal joint system. Lesser jointing at approximately 45 degrees is common and occasional near-vertical joints were noted. The joint planes are described as smooth and commonly coated with dark pyrite. The jointing often extends completely across the shaft giving the appearance of bedding.

The water-bearing limestone cap rock unit has been intersected in drill holes flanking the dome to a depth of 320 meters (1,050 feet) below sea level, or 640 meters (2,100 feet) from the surface. The limestone cap rock has yielded measurable quantities of fresh water at this depth. The relatively low contamination of the ground water at such a depth may indicate high recharge and/or good isolation from the salt stock. It is possible that the Hockley dome is subject to only minimal dissolution from ground water.

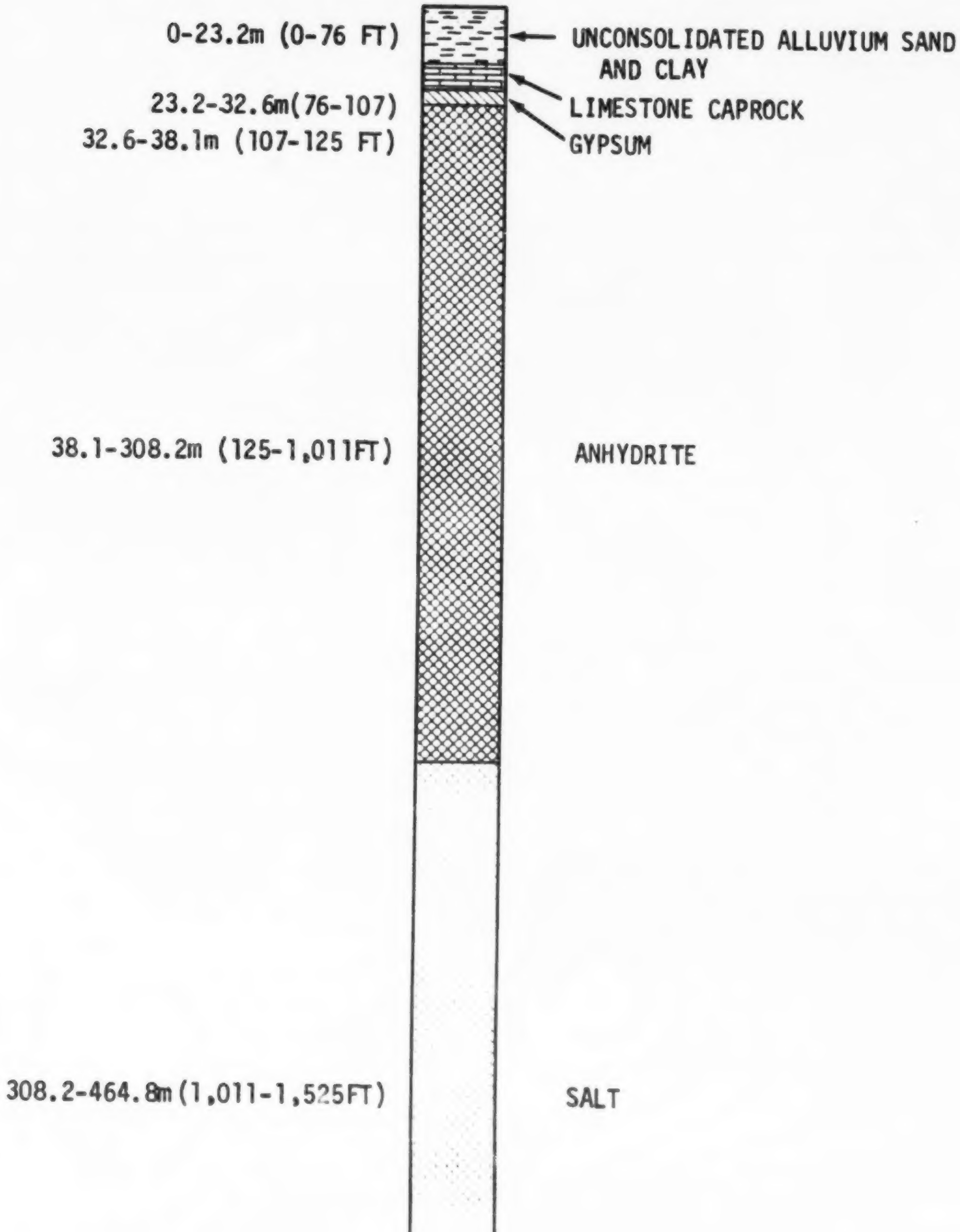

0-23.2m (0-76 FT)
UNCONSOLIDATED ALLUVIUM SAND AND CLAY
23.2-32.6m(76-107)
LIMESTONE CAPROCK
32.6-38.1m (107-125 FT)
GYPSUM
38.1-308.2m (125-1,011FT)
ANHYDRITE
308.2-464.8m (1,011-1,525FT)
SALT

Figure 16. Stratigraphic Column - Hockley Shaft.

The Hockley Dome is located in a historically quiet seismic area, having a rating of 0 on the Seismic Risk Map. No major mining problems are evident at the Hockley Mine.

Grande Saline

The Morton Salt Company mines salt from the Grande Saline salt dome which is located about 105 kilometers (65 miles) east of Dallas, Texas. Indians were known to use salt originating from local brine springs prior to 1845, but the source of the salt was not discovered until 1888. The Grande Saline Salt Company discovered the rock salt mass and produced salt from brine wells until the late 1800's.

In 1930, the Morton Salt Company commenced sinking a shaft for the purpose of conventionally mining the salt. In 1931, the original 4.4 meter (14.5 foot) diameter shaft was completed to a depth just below the working level at 213.4 meters (700 feet) below the surface. The collar of the shaft is 119.5 meters (392 feet) above sea level. Production figures are not readily available, but a production capacity of 907 metric tons (1,000 tons) per day was found in the literature. The volume of mined space is unknown, but is assumed to be quite extensive.

The Grande Saline salt dome is located in the Interior Subprovince of the Gulf Coast Embayment, forming in the deep East Texas Syncline structural trough. Exploratory drilling has indicated that the dome is shaped like a truncated cone with a nearly flat top averaging about 64.6 meters (212 feet) below the surface. The diameter of the dome is roughly 2,438 meters (8,000 feet) at the top. Surface expression of the dome is as a roughly circular depression forming a swampy, saline lake.

Near surface deposits at Grande Saline are Tertiary beds composed of sand, clay, and shale which grade into a soft sandstone. At about 57.9 meters (190 feet) in depth, there is a cap rock formation of cavernous limestone which contains a large quantity of salt water. Underlying the limestone and immediately above the salt there is about 1.5 meters (5 feet) of impermeable anhydrite. Large quantities of ground water are available from the sandy and limy formations overlying and lapping the Grande Saline salt dome.

The Grande Saline Dome lies along the dividing line separating 0 and 1 risk zones on the Seismic Risk Map. Both the low seismicity and an apparent lack of diapiric movement indicate good stability at this site. Some difficulties were encountered while sinking the shaft through the water-bearing strata. Since completing the shaft, the mine has been relatively free of major problems related to stability or flooding.

Cote Blanche

Rock salt is mined from the Cote Blanche salt dome by Domtar Chemical Company. Cote Blanche Island is located in the western part of St. Mary's Parish, 32 kilometers (20 miles) south of New Iberia, Louisiana. Exploration for salt on Cote Blanche began as early as 1862 after rock salt was discovered on Avery Island. The Southern Salt Syndicate was organized in the spring of 1921 to find and mine salt on Cote Blanche. Fifty-four exploratory holes were drilled during the next year. The highest point of the salt was found to be 90.8 meters (298 feet) below the surface and 90.5 meters (297 feet) below water level. Because of anticipated water problems and difficulties with property leases, the Southern Salt Syndicate did not attempt to sink a shaft. The Carey Salt Company acquired the lease on Cote Blanche and began sinking a shaft in 1963. Mining of the salt has been continuous since operations began in 1964.

Access to the mine is through two shafts, one 2.4 meter (8 foot) diameter service shaft and one 4.3 meter (14 foot) diameter production shaft to a total depth of 427 meters (1,400 feet). The mining level at the service shaft is 415.1 meters (1,362 feet) below the surface. The salt is mined in two benches by room and pillar methods. The completed rooms are 15.2 meters (50 feet) high and all entries and crosscuts in the production areas are on 45.7-meter(150-foot) centers.

Cote Blanche Island is the surficial indication of the underlying salt dome. The island rises to a maximum elevation of about 30.5 meters (100 feet) above sea level and is about 3.2 kilometers (2 miles) in diameter. It is surrounded by marsh except for the south edge which opens onto Cote Blanche Bay.

Salt at the Cote Blanche dome is over 99 percent sodium chloride; present as alternating white and gray bands. The darker bands of halite result from small amounts of impurities. Anhydrite (calcium sulphate) is the most common impurity found in the salt.

No cap rock has been found at the Cote Blanche salt dome. The top of the salt is overlain by alluvial deposits of sand, gravel, and clay. The dome is relatively smooth and no indication of severe overhangs have been found. A fault with the downthrown side to the northwest is found in the surficial deposit on the south side of the island. The fault is believed to have formed as a result of dissolution of the underlying salt.

Ground water is found in large amounts in the alluvial deposits above the salt at Cote Blanche. Several water-bearing sands were encountered while sinking the shafts into the salt. One water-bearing sand was found immediately on top of the salt and another sand, containing approximately 30 percent water by volume, was encountered at a depth of 143.3 meters (470 feet). Ground water is also present in some of the formations that were pierced as the dome formed. Flooding of the mine might result if communication is ever established between these water-bearing formations and the mine workings.

There has been no report of any stability or water inflow problem at the Cote Blanche mine. The mine is located in a low risk seismic zone, indicating minor damage from earthquakes during the historic past.

Avery Island

The International Salt Company produces salt from Avery Island which is located about 161.1 kilometers (10 miles) southwest of New Iberia, Louisiana. Salt was produced from brine springs as early as the late 1700's. The first commercial development of the salt springs was in 1812 by John C. Marsh, the owner of the island. Production continued for several years until competition from imported salt forced the closing of the plant. The beginning of the Civil War prompted the reopening of the salt works by John Marsh Avery, grandson of John C. Marsh. Rock salt was discovered on May 6, 1862 when the brine wells were being cleaned and deepened. Following this discovery, salt was produced from open pits until April 17, 1863 when Federal forces captured and destroyed the works.

In 1867 Chouteau and Price sunk the first shaft into the salt. The shaft was 27.4 meters (90 feet) deep and extended about 17.7 meters (58 feet) into the salt. Operations continued until 1870 when Mr. Price died and Mr. Chouteau abandoned the mine. The mining rights were leased by the Galveston Company in 1879 and in 1880 they were transferred to the American Salt Company. Salt was produced from the existing shaft, until 1885. Because of the development of sinkholes that connected with the 27.4 meter (90 foot) level, the shaft was deepened 21.3 meters (70 feet) and new workings were started 48.8 meters (160 feet) below the surface. The New Iberia Salt Company replaced the American Salt Company in 1886. Salt was produced from the newer working level by mining rooms 24.4 meters (80 feet) wide and 12.2 meters (40 feet) high. The pillars that were left to support the roof were 18.3 meters (60 feet) in diameter. In 1893, the New Iberia Salt Company subleased the property to Myles and Company, of New Orleans. Water entering the upper level penetrated to the lower level and forced the abandonment of the lower level in July, 1895 and the upper level in 1896.

The Avery Rock Salt Mining Company was organized in 1898 to produce salt from the old workings and to construct a new shaft. After exploratory drilling, a site for a new shaft was selected beyond the southwest limits of the old mine. To prevent recurrence of the water problems that developed in the old mine, the new shaft was sunk to a depth of 157.9 meters (518 feet). When the new shaft was completed in 1899, the International Salt Company acquired the Avery Island salt mining operations.

The International Salt Company's production shaft is 6.4 by 3 meters (21 by 10 feet) and divided into three compartments. Surface elevation of the shaft is 9.4 meters (31 feet) above sea level. The present mine level is 161.5 meters (530 feet) below the surface and 152.1 meters (499 feet) below sea level. A second shaft for ventilation was completed in 1920.

Salt is mined by conventional room and pillar methods. The working face is 30.5 meters (100 feet) across and 27.4 meters (90 feet) high. Total production figures have not been released by the International Salt Company, but the annual production has been estimated at over one million tons, which would be equal to approximately 413,000 cubic meters (14.6 million cubic feet) of mine volume per year.

The International Salt Company's Mine at Avery Island is in a typical coastal salt dome. In plan view, the dome is nearly oval in shape and about 2.4 kilometers (1 1/2 miles) in diameter. Maximum elevation of the island is 46.3 meters (152 feet). The island is surrounded by low lying marshland. In some areas, the top of the salt is within 4.9 meters (16 feet) of the surface. The salt stock is fairly flat on top and there is little indication of major cap rock development. No cap rock was found when the first shaft was sunk in 1867. The salt that is mined at Avery Island is white to light gray halite, 99 percent sodium chloride. It is dense, opaque, microcrystalline, and flow banded. The salt contains inclusions of red sandstone and a small amount of other evaporites.

Oil and gas has been produced from the flanks of the dome. The oil accumulated in stratigraphic traps formed by the rupturing of the lower formations as the dome formed. Some of these formations contain considerable amounts of water and flooding of the mine might occur if the edge of the dome is penetrated by mining or drilling. The top of the salt dome is overlain by water-saturated sand, gravel, and clay deposits. The water table at the site of the old mine shaft was 7.3 meters (24 feet) below the surface and the top of the salt was 16.5 meters (54 feet) deep. When salt was mined on the 27.4 meter (90 foot) level, open fractures were developed between the mine and the overlying water table. As a result of water seeping down these fractures, sink holes were developed as early as 1883, and eventually prevented operations out of the original mine shaft.

The Avery Island dome is in seismic risk zone 1, indicating low intensity earthquakes causing only minor surface damage.

Weeks Island

The Morton Salt Company mines rock salt by the room and pillar method at the Weeks Island salt dome. Weeks Island is located 24.1 kilometers (15 miles) south of New Iberia, Louisiana.

After the discovery of salt on Avery Island in 1862, several unsuccessful wells were dug on Weeks Island in the search for salt. Salt was not found on Weeks Island, however, until July of 1897, when Mr. F. F. Myles had 14 exploratory holes drilled. The Myles Salt Company was formed in 1898 and 14 more exploratory holes were drilled to determine the best area for the mining of the salt. Construction of the first shaft was started in July of 1898. Production did not begin until March of 1902 because of water problems encountered while constructing the shaft. The Myles Salt Company merged with the Morton Salt Company in 1948.

The original shaft was 3.5 meters (10 feet) in diameter and 196.6 meters (645 feet) deep. The floor level of the mine was 163.1 meters (535 feet) below sea level. This level, which is now abandoned, had rooms 18.3 to 27.4 meters (60 to 90 feet) high. The present mining level is 231 meters (758 feet below the surface and 208.5 meters (684 feet) below sea level. The salt is mined by multiple bench, room and pillar methods. Depending on which bench is being mined, the rooms vary in height from 7.6 to 27.4 meters (25 to 90 feet).

Weeks Island is the top of a coastal salt dome. It is about 3.2 kilometers (2 miles) in diameter and the maximum elevation is 41.1 meters (135 feet) above sea level. Little indication of cap rock development has been found at Weeks Island. The salt which rises to within 26.8 meters (88 feet) of the surface is overlain by beds of sand, gravel, and clay.

The salt is over 99 percent halite. In some areas, bands of very pure white salt alternate with darker, less pure salt bands. The darker colored bands result from the presence of impurities of 2 to 4 percent anhydrite.

As in the case of most salt domes, water could present a serious problem at the Weeks Island Mine. Large amounts of water are present in the surficial sand and gravel beds and in the subsurface beds penetrated by the dome. Flooding of the mine working could result if the edge of the dome was ever breached.

Weeks Island, like the others in the Five Islands group is in a low intensity seismic risk zone.

Jefferson Island

The Diamond Crystal Salt Company's Jefferson Island mine is located about 14.4 kilometers (9 miles) west of New Iberia, Louisiana.

In reality, Jefferson Island is not truly an island, since it is not surrounded by water. The name is derived from its resemblance to the other domes in the Five Islands group. The maximum elevation of Jefferson Island is 22.9 meters (75 feet) above the surrounding plains and the area of the Island is about 1,212 square kilometers (300 acres).

The first attempt at mining the salt at Jefferson Island was in 1919 when the Jefferson Island Mining Company started sinking a shaft. The shaft was lost at the top of the salt when flooding occurred. In 1920, a new shaft was started but continuous production did not begin until 1922 when water leaks around the shaft were sealed off. Production in 1973 was 1,497,870 metric tons (1,650,000 tons) which is equivalent to about 680,000 cubic meters (24 million cubic feet). The original shaft entered the salt 12.2 meters (40 feet) below sea level and 30.5 meters (100 feet) below the surface of the ground. The diameter of the shaft was 7.6 meters (25 feet) and its depth was 274.3 meters (900 feet). The working level was 243.8 meters (800 feet) below the surface.

Jefferson Island is a typical coastal salt dome. Cap rock has been found in only a few exploratory holes and consists of 45.7 to 60 centimeters (18 to 24 inches) of gray limestone. The majority of the overlying material is sand and gravel with a few scattered lenses of clay. Salt from domes is very pure, usually over 99 percent sodium chloride. The salt at Jefferson Island tends to be somewhat lighter in color and firmer than salt from the rest of the Five Islands group.

Possible water problems might be encountered at the Jefferson Island salt mine because the top of the dome is overlain by water-bearing sand and gravel deposits and the north-west edge of the dome is under Lake Peigneur.

Jefferson Island is located in zone 1 on the Seismic Risk Map of the United States.

Belle Isle

Cargill Incorporated mines salt from the Belle Isle salt dome, which is located 30.6 kilometers (19 miles) southeast of Franklin, Louisiana. After the discovery of salt on Avery and Jefferson Islands, exploration for salt was started on the other domes in the Five Islands group. Exploratory drilling on Belle Isle was started in November, 1896 by Captain A. F. Lucas. The first drill hole encountered salt at a depth of 113.7 meters (373 feet) in December of 1896. After drilling fourteen exploratory holes during 1896 and 1898, the Gulf Company began sinking a mine shaft in August, 1889. The shaft was completed to a depth of 118.8 meters (390 feet) and a heading was driven eastward for 103.6 meters (340 feet). At this point, water poured in and within two hours completely flooded the workings.

A second shaft was started 0.4 kilometers (1/4 mile) southwest of the original workings, but it was abandoned at a depth of about 60.9 meters (200 feet) because of problems with quicksand and soft clay. After the loss of the second shaft, an attempt was made to produce salt by solution mining. This process was abandoned because of impurities in the salt and the possibility of caving of the unconsolidated overburden. No salt was produced again from Belle Isle until 1963, when Cargill

Incorporated began mining salt from a depth of about 365.7 meters (1,200 feet).

Belle Isle is roughly triangular in shape and rises to a maximum elevation of 24.4 meters (80 feet) above the surrounding marshes and bayous. The top of the salt at the highest point is 41.8 meters (137 feet) below the surface and cap rock is 33.5 meters (110 feet) below the surface. Salt near the surface at Belle Isle is less pure (approximately 93-96% sodium chloride) than the salt from the others of the Five Island group, (98-99 percent sodium chloride), but the purity increases with depth.

The cap rock is better developed at Belle Isle than all the other domes in the Five Islands group. Some of the holes drilled into the Island penetrate over 152 meters (500 feet) of gypsum, anhydrite, and sulfur immediately above the salt. Surficial deposits, consisting of interbedded sand, gravel, and clay, vary considerably in thickness because of uneven dissolution of the top of the salt stock. As is common with most salt domes, large amounts of water are present in the formations surrounding the Belle Isle salt dome.

Since Cargill Incorporated began mining operations at Belle Isle, the most serious problem that has been reported occurred on March 3, 1973 when partial flooding of the mine workings resulted from water inflow around the No. 2 Shaft. Subsidence of the surface facilities near the collar of the shaft occurred due to the great volume of material removed from around the shaft by the flowing water. Mining operations have been suspended at Belle Isle until the No. 2 Shaft can be rehabilitated.

Belle Isle is also located in a low risk seismic area.

Limestone Mines

In the Kansas City, Missouri area, favorable geological conditions associated with the Bethany Falls Limestone Member of the Kansas City group have led to the development of extensive underground space that is suitable for storage. There is approximately 11 million square meters (120 million square feet) of underground space in an area within a radius of 40 kilometers (25 miles) of downtown Kansas City. Of this amount of space, 1.4 million square meters (15 million square feet) is currently being used and another 2.8 million square meters (30 million square feet) is suitable and available for use. Currently, one seventh of Kansas City's warehouse space is located underground in converted limestone mines. Most of this space is developed in the Bethany Falls limestone.

Mining of the Bethany Falls limestone began in the late 1800's to supply construction material for the industrial development of the Kansas City area. The Bethany Falls was initially quarried along the outcrop of the limestone in the larger stream valleys. When the thickness of the overburden became too great to be economically stripped from the top of the limestone, horizontal entrances were constructed and underground mining by room and pillar methods was started.

Extensive mining of the Bethany Falls and the use of the mined out space for storage resulted from a combination of several geological factors. Rock has been produced from the Pennsylvanian Bethany Falls Limestone Member because it is one of the few formations in the area that contains limestone which will meet the requirements for highway and other types of construction. The limestone bed is almost horizontal and is present below most of Kansas City and the surrounding area. The dip of the bed is about 2 to 4 meters per kilometer (10 to 20 feet per mile) to the north.

The Bethany Falls is light to dark gray, fine-grained to crystalline, mottled limestone with massive bedding at the top and thin bedding near the base. Joints in the Bethany Falls are tightly closed, nearly vertical, and discontinuous. The joints trend N 60°E to N 70°E and the joint spacing averages 16.5 meters (54 feet). The joint spacing decreases as the outcrop is approached. A well defined bedding plane, 1.2 to 1.8 meters (5 to 6 feet) below the top of the unit, eases the construction of a smooth stable roof for the rooms. In the metropolitan Kansas City area an overlying strata thickness of over 61 meters (200 feet) prevents the weakening of the roof by weathering processes.

Ground water is not a serious problem in the mined openings of the Bethany Falls limestone. Impermeable shale beds above and below the Bethany Falls prevent water movement into the limestone. The only ground water entering the workings are from small seeps near the outcrops and from seepage around rock bolts that penetrate the overlying strata.

The Bethany Falls Limestone in the Kansas City, Missouri area is currently being mined by underground methods at about a dozen mines. New underground space is being created at a rate of about 485,000 square meters (120 acres) per year.

An example of a limestone mine that would be less desirable for storage purposes, because of geological/hydrological factors, is the Kimballton Limestone Mine of Standard Lime and Cement Company in Giles County, Virginia.

The Standard Lime and Cement Company produces over 1,545 metric tons (1,700 tons) per day of high purity limestone from the Ordovician Five Oaks Member of the Cliffield Formation. The high-calcium limestone is burned for conversion to lime.

There are a combination of factors why the Kimballton Limestone Mine would be less desirable than other mines for underground storage and these are:

1. Regional tectonics have deformed the Five Oaks limestone bed in the Kimballton area. The bed is gently undulated and dips about 15 degrees to the southeast.

2. Numerous interload tension fractures were formed by the warping of the bed. Many of the fractures have been healed by calcite, but some of the fractures are open and lined or filled with red clay or silt.

3. Two faults have been excavated during mining operations at the Kimballton Mine. The total vertical displacement along the faults is about 15.2 meters (50 feet). In the area of the faults the level of the floor had to be lowered in order to continue operations.

4. Large amounts of water can enter the mine along old water channels shortly after heavy rains. The existence of a water filled channel that connects with the mine has forced the abandonment of the lower working of the mine. The abandoned workings are now used as a sump. Water is almost continuously pumped from the sump to the surface at a rate of 13,200 liters (3,500 gallons) per minute to prevent flooding of the workings.

"Hard Rock" Mines

There are 30 to 35 mines throughout the continental United States presently active in recovering metallic and industrial minerals by room and pillar methods. The minerals mined consist of ores for antimony, barite, copper, fluorspar, iron, lead-zinc, silica, and talc. The most numerous of the hard rock mines are those from which lead-zinc ores are recovered.

Most of the detailed information concerning these mines is held, either in confidential files or as unpublished information, by the mining companies. However, some general characteristics of room and pillar hard rock mines and the range of conditions which may occur can be described.

Mineral occurrences suitable for room and pillar mining are bedded deposits often in or associated with limestone or dolomite horizons of sedimentary basin structures. Metallic element mineralization occurs as irregular bands, lenses, and fine disseminations of ore minerals in limestone or shaly limestone horizons. Structure of these deposits vary from very complex to simple. Faulting is commonly present and developed to any degree, from occasional gravity faults with minor displacement, to major shear zone intersectors where ore has been moved great distances.

Hydraulic problems vary from minor to extreme. Mines in the Picher field of Oklahoma and Kansas incorporate vast areas of room and pillar excavation, now mined out, which have been allowed to flood and now are filled with water. Quite often the structural features such as faults, joints, and bedding plane permeability which allow ore bearing solutions to form the deposit remain open and thus allow ground water to invade a mine.

An example of a lead-zinc mine active in 1964 is the Young mine of Jefferson County, Tennessee. The Young mine ore body is a domed sloped structure varying from 183 to 246 meters (600 to 808 feet) below the surface and roughly 1.5 kilometers (one mile) in diameter. The ore zone varies from 21 to 30.5 meters (7 to 100 feet) thick and consists of zinc sulfide-sphalerite. Between 1955 and 1964 some 4,535,900 metric tons (5,000,000 tons) of ore was mined. The mining method is trackless room and pillar development of the ore body with systematic placement of chutes from the ore body to haulage drifts developed below the ore zone. Transport on the haulage level is by rail. All leakage and drilling water, about 757 liters/minute (200 gallons/min) of which probably 379 liters/minute (100 gallons/min) is leakage, runs to a central sump and is pumped to the surface.

As the mine appears in the 1964 report, it is divided into four separate sections with one or two interconnected passages, thus allowing compartmentalization.

It must be pointed out that when considering metal mines having a relatively high product value, a change in the price of metal may alter the configuration of the future development of a mine allowing the extraction of lower grade ores in times of high metal prices. Mines are frequently reopened several times during their existence, especially those whose limits are determined by economic cut off ore grades.

EVALUATION OF GEOLOGIC ENVIRONMENTS

The suitability potential of several geologic environments can be augmented by illustrating those areas of the United States which presently have mined storage of liquid petroleum products. Figure 17 shows the location of LP-Gas storage caverns in various rock mediums. All were mined using room and pillar methods in lithologies which were found to be essentially impervious and well isolated. An important requirement at most of these sites was that the product be stored under pressure. The success of these caverns, which have an aggregate volume of more than 1,700,000 cubic meters (60,000,000 cubic feet), demonstrates that secure containment is possible in carefully selected underground environments.

The investigations of salt and other underground environments have highlighted many of the characteristics which can be either beneficial or detrimental to the underground storage of hazardous chemical wastes.

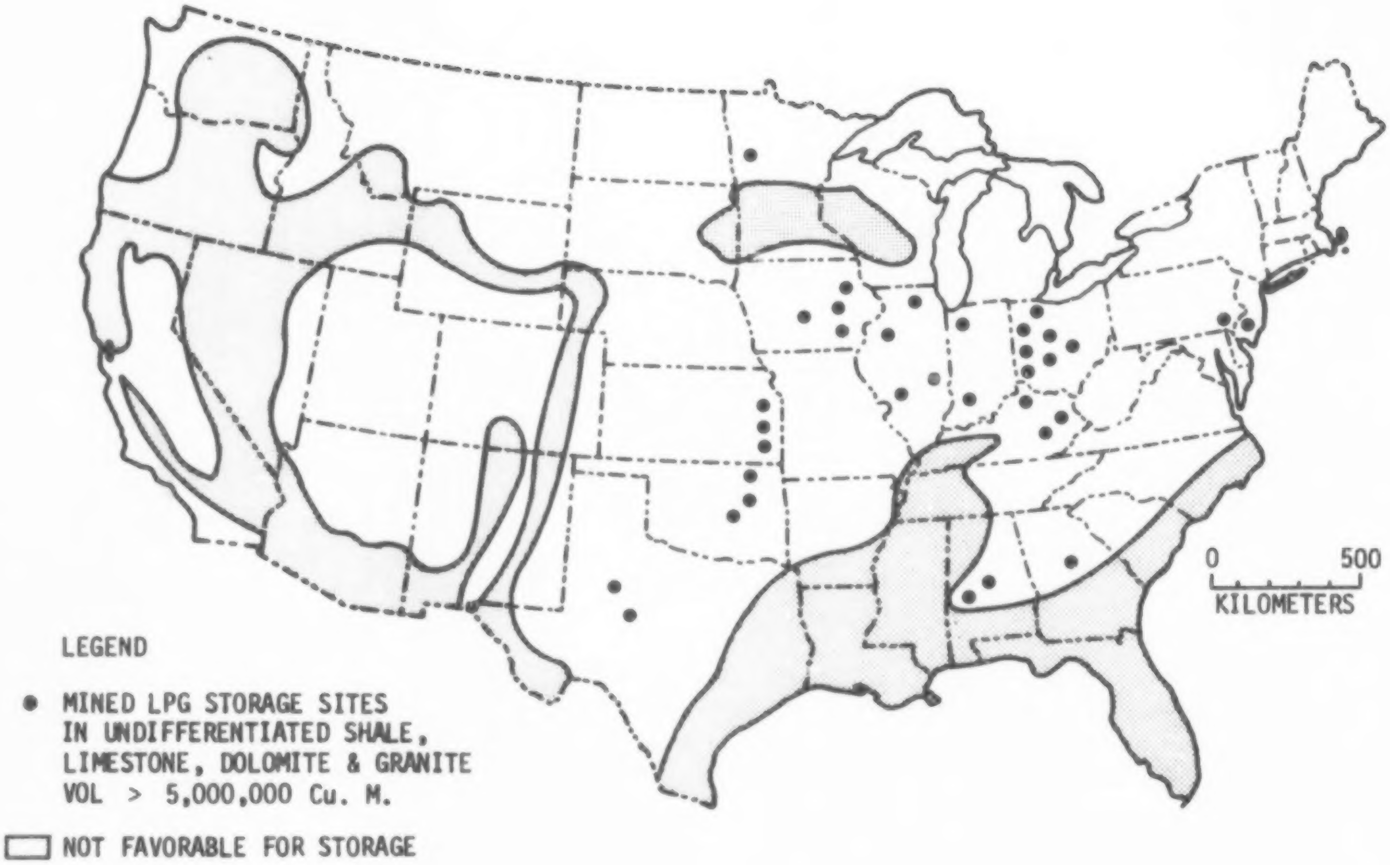

0
500
KILOMETERS
LEGEND
● MINED LPG STORAGE SITES IN UNDIFFERENTIATED SHALE, LIMESTONE, DOLOMITE & GRANITE VOL > 5,000,000 Cu. M.
▭ NOT FAVORABLE FOR STORAGE

Figure 17. Mined Liquid Petroleum Gas Storage in the United States.

Following is a summary of these characteristic features, with a subjective analysis of their significance to underground waste storage.

Salt

Salt deposits are widely distributed and commonly mined using room and pillar methods. In general, salt environments are impervious to water and well isolated from aquifers. Salt is a competent structural material, not often subjected to severe seismicity or faulting. Bedded salt deposits are less subject to severe water problems than salt domes. Natural salt deposits are very pure allowing excellent reactivity analysis. Depths, thicknesses, and inclination are all favorable for storage. Salt is self-healing and behaves plastically, which acts to reduce mining hazards and allows easy reexcavation and maintenance of mined openings. Salt is not subject to alteration, but is readily soluble in water. Surface relief and access to bedded salt environments are good. Certain salt environments should be very good for hazardous waste storage.

Gypsum

Gypsum deposits are widely distributed and sometimes mined by room and pillar methods. Physical characteristics are good, but thin bedding and near surface occurrences will limit the utility of gypsum environments by reasons of isolation, structure, maintenance, etc. Gypsum is soluble in acids and ammonium salt solutions. If carefully chosen, certain gypsum deposits should be found suitable for hazardous waste storage.

Potash

Potash is similar to salt with these exceptions: limited occurrence, higher economic value, and greater extraction ratios. Potash, like salt, has a very good potential for storage.

Shale

Shale environments are widely distributed. Shales are essentially impervious and are effectively isolated from water when very thick. Depth and inclination are often satisfactory. Ion exchange capacity is a potentially beneficial characteristic of shales. Shales have limited plasticity under stress. Structural problems are often related to thin bedding. Shales are not commonly mined. Montmorillonite rich shales absorb fluids and expand, thus limiting integrity and stability. Shales have limited potential for mined waste storage.

Limestone

Limestones are widely distributed and commonly mined using room and pillar methods. Limestone environments in wet climates are often wet due to solubility. Plastic behavior is minimal; however, competence and stability are good when bedding is massive and structure is undisturbed by faulting, fracturing, etc. Isolation from water is most likely in dry climates. Calcium carbonate in limestones is reactive with acids, and strong ammonium salts such as ammonium chloride, nitrate and sulfate. Some limestone environments may be found suitable for hazardous waste storage, particularly in arid regions.

Granite

Granite and related intrusives occur in areas where the other lithologies do not occur. Strength and impermeability, when not fractured, are excellent. Room and pillar mining is possible but is used only for special purpose storage. Seismic risk is commonly greater in granite areas, as are fracturing and faulting. Erosion and alteration act slowly. Surface relief and access are locally limited. In certain areas granite environments should be found suitable for mined storage of hazardous wastes.

Preliminary Decision Model - Waste Storage Mines

To facilitate the evaluation of these, or other, lithologic environments and mined openings, a preliminary decision model has been developed and is presented in Figure 18. Using this model it is possible to screen any mined environment for preliminary suitability. By subjecting all potential underground storage sites to this screening technique as the information becomes available, it will be possible to arrive at a listing of the most promising sites. These sites can be further evaluated and subjectively compared using the method presented below.

Value Judgment Rating

The results of the geologic investigation indicate that certain lithologic environments are more suitable for hazardous waste storage with respect to the established criteria. In order to relatively compare and rank each lithosphere, a value judgment rating matrix was developed, and is presented in Table 2.

On the upper half of the two-part matrix the fundamental suitability criteria and the seven lithologic environments are listed. In addition, there is an "ideal" heading which represents a perfect underground environment for hazardous waste storage. This "ideal" environment would fulfill all of the designated criteria 100 percent when mined.

Beneath all of the studied environments, there are numbers assigned to represent their potential for fulfilling each of the listed criteria. These are shown as a percent of the "ideal". For instance, bedded salt is listed as having the potential to be 90 percent of the "ideal" (dry and impervious) condition when mined, while granite has only 40 percent potential.

The percent values listed would normally be conservative if only

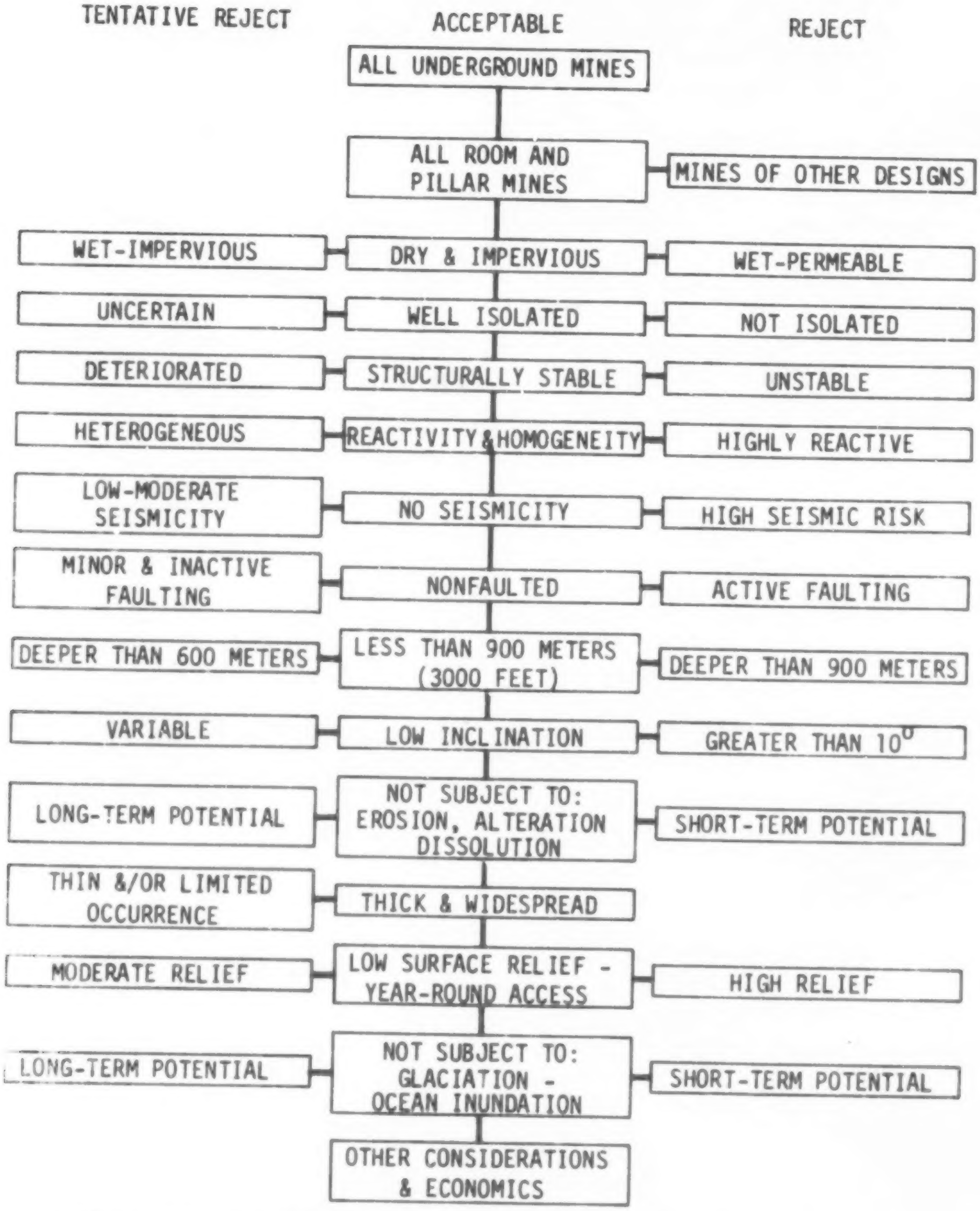

TENTATIVE REJECT
ACCEPTABLE
REJECT
ALL UNDERGROUND MINES
ALL ROOM AND PILLAR MINES
MINES OF OTHER DESIGNS
WET-IMPERVIOUS
DRY & IMPERVIOUS
WET-PERMEABLE
UNCERTAIN
WELL ISOLATED
NOT ISOLATED
DETERIORATED
STRUCTURALLY STABLE
UNSTABLE
HETEROGENEOUS
REACTIVITY & HOMOGENEITY
HIGHLY REACTIVE
LOW-MODERATE SEISMICITY
NO SEISMICITY
HIGH SEISMIC RISK
MINOR & INACTIVE FAULTING
NONFAULTED
ACTIVE FAULTING
DEEPER THAN 600 METERS
LESS THAN 900 METERS (3000 FEET)
DEEPER THAN 900 METERS
VARIABLE
LOW INCLINATION
GREATER THAN 10°
LONG-TERM POTENTIAL
NOT SUBJECT TO: EROSION, ALTERATION DISSOLUTION
SHORT-TERM POTENTIAL
THIN &/OR LIMITED OCCURRENCE
THICK & WIDESPREAD
MODERATE RELIEF
LOW SURFACE RELIEF - YEAR-ROUND ACCESS
HIGH RELIEF
LONG-TERM POTENTIAL
NOT SUBJECT TO: GLACIATION - OCEAN INUNDATION
SHORT-TERM POTENTIAL
OTHER CONSIDERATIONS & ECONOMICS

Figure 18. Preliminary Decision Model - Waste Storage Mines.

Table 2. VALUE JUDGEMENT RATING

	Criteria		Lithologic Environments							
		Wt. Value	Salt		Gypsum	Potash	Shale		Lime-stone	Granite
			bed	dome			"1"	"2"		
			*	*	*	*	*	*	*	*
Percent of Ideal	Dry & Impervious		90	80	70	90	70	80	50	40
	Isolated		100	70	50	100	60	60	60	60
	Stability & Structure		90	80	60	90	10	20	50	80
	Reactivity & Homogeneity		90	90	90	90	30	40	40	60
	Seismicity & Faulting		90	90	60	90	60	60	50	50
	Competence & Strength		80	70	60	80	20	30	70	90
	Alteration - Dissolution		70	50	70	70	30	40	40	80
	Depth - Inclination		90	90	80	90	70	80	70	80
	Erosion		90	90	60	90	60	70	70	80
	Thickness & Distribution		90	80	60	70	70	70	60	80
	Relief & Access		100	70	80	90	80	80	70	60
	Glaciation - Inundation		70	20	70	80	60	70	70	70
			**	**	**	**	**	**	**	**
Suitability	Dry & Impermeable	18	16.2	14.4	12.6	16.2	12.6	14.4	9.0	7.2
	Isolated	15	15.0	10.5	7.5	15.0	9.0	9.0	9.0	9.0
	Stability & Structure	12	10.8	9.6	7.2	10.8	1.2	2.4	6.0	9.6
	Reactivity & Homogeneity	12	10.8	10.8	10.8	10.8	3.6	4.8	4.8	7.2
	Seismicity & Faulting	12	10.8	10.8	7.2	10.8	7.2	7.2	6.0	6.0
	Competence & Strength	9	7.2	6.3	5.4	7.2	1.8	2.7	6.3	8.1
	Alteration - Dissolution	5	3.5	2.5	3.5	3.5	1.5	2.0	2.0	4.0
	Depth - Inclination	5	4.5	4.5	4.0	4.5	3.5	4.0	3.5	4.0
	Erosion	3	2.7	2.7	1.8	2.7	1.8	2.1	2.1	2.4
	Thickness & Distribution	3	2.7	2.4	1.8	2.1	2.1	2.1	1.8	2.4
	Relief & Access	3	3.0	2.1	2.4	2.7	2.4	2.4	2.1	1.8
	Glaciation - Inundation	3	2.1	0.6	2.1	2.4	1.8	2.1	2.1	2.1
	Suitability Value (%)		89.3	77.2	74.0	88.7	48.5	55.2	54.7	63.8

Shale "1" = montmorillonite rich

Shale "2" = montmorillonite poor

* = Percent

** = Percent of Ideal x Wt. Value

considering a single, well-chosen site within a given lithologic environment because the environments shown represent a composite of all the occurrences, and thus include both the best and worst natural conditions.

The lower matrix was developed to subjectively rank the lithologies as compared to the "ideal". In this matrix each of the criterion have been assigned a weighted value to indicate its relative importance to a complete suitability assessment. The percent ideal values listed under each lithologic environment in the upper matrix, times the "weighted value" assigned to each criterion gives the "percent suitability" values shown in the lower matrix.

For instance, bedded salt with a 90 percent of "ideal" in the upper matrix has a 16.2 "percent suitability" in the lower matrix, which is 90 percent of the weighted value (18) assigned to the criterion, "Dry and Impervious."

By totaling all of the "percent suitability" values listed under each lithosphere, a total "suitability value" was obtained for each environment and is shown as a percent of the "ideal" environment.

On the basis of this evaluation, bedded salt is accorded the highest percent suitability (89.3 percent), closely followed by potash, (88.7 percent). Domal salt, (77.2 percent), and gypsum (74.0 percent) are ranked third and fourth followed by granite (63.8 percent), shale "2" (55.2 percent), limestone (54.7 percent) and shale "1" (48.5 percent). These values indicate the potential for each of these lithospheres to meet the suitability criteria, if mined for this purpose. They do not represent past or present mining operations, methods, or conditions.

All of the assigned values were subjectively selected to reflect the relative geologic suitability of each lithology as an environmentally acceptable medium for storing hazardous wastes. Other researchers may evaluate the geological suitability differently, however, it is unlikely that the relative rankings will change significantly. By the addition of economic and other parameters which are not within the scope of this study, this rating matrix could be developed into an even better decision making tool.

SECTION 6

WASTE CHARACTERIZATION

The characterization of the wastes was primarily concerned with determining the environmental acceptability of the wastes for underground storage according to their hazards. This determination was approached from three main viewpoints:

1. An investigation of the physical, chemical, and hazardous properties of the wastes to assess their acceptability for underground storage before and after treatment.

2. The control of possible environmental contamination through proper treatment and containerization.

3. An investigation of possible environmental degradation which may occur after storage from the chemical interaction of the wastes with each other and with the geological formations or from waste migration.

From a review of existing literature, it quickly became evident that previous studies have been primarily concerned with identifying and analyzing the most hazardous constituents in waste streams rather than a total waste stream analysis. This type of analysis has been called the "pure-form" approach and assumes the properties of a total waste-stream to be identical to those of its most hazardous constituent. Although the most realistic characterization of wastes will require a total waste-stream analysis, it was necessary to use the "pure-form" approach due to the lack of available information on total waste streams. However, the methodology for analysis that was developed can be applied equally well to either "pure-form" wastes or waste-streams. As additional waste-stream data is obtained, new candidates for storage in underground mines can be realistically screened using the developed methods.

The wastes considered as candidates for underground storage were non-radioactive industrial wastes presenting special problems in treatment or handling. A literature review revealed that such wastes had been identified in a previous study. This study analyzed over 500 hazardous industrial wastes and classified them by the following disposal methods:

1. Municipal
2. Industrial
3. National Disposal Sites (NDS)

Since the 115 wastes requiring NDS disposal were those presenting special problems, they were considered as the candidate wastes for storage in a mined facility.

The environmental acceptability of a hazardous waste underground depends upon the level of hazard it presents prior to storage. A waste must be evaluated with respect to potential effects on the biosphere resulting from its handling, treatment, storage, or possible migration. If it was found that a waste was too hazardous to the environment in its pure form, then its hazards could, in most cases, be reduced through treatment. The treatment procedures, as presented in this report, are theoretical in nature. Since an investigation of the engineering design required to carry out these procedures was not within the scope of this study, it is recommended that this type of work be done to confirm the practicality of the methods presented.

It was assumed, for the purposes of this study, that each waste would be containerized for storage. This assumption was based upon many factors. From an environmental standpoint, the containerization of the wastes would provide maximum safety during handling and storage while minimizing the potential for contamination of the biosphere through migration. In addition, if it became feasible to recycle a waste or an environmental calamity was eminent, containerization would allow a waste to be retrieved from storage without danger. For these reasons, it was concluded that hazardous wastes should be stored in mines according to the Bureau of Mines safety requirement 30 CFR, Chapter 1, part 57, 16-4 which reads as follows: "Mandatory - Hazardous materials shall be stored in containers of a type approved for such use by recognized agencies; such containers will be labeled appropriately." It is recommended that research be undertaken to determine the type of container or encapsulation which would meet the requirements of underground storage.

In order to further analyze potential hazards to the environment after storage, it was assumed that the containers would be ruptured by some force allowing the wastes to contact the mine environment. This type of "worst case" philosophy was continued throughout the investigation whenever an assumption as to conditions was to be made. It should be remembered, however, that with proper treatment and containerization, the probability of container rupture or waste migration is very slight.

As a final step in characterizing the wastes, the magnitude of the waste problem was assessed by compiling current volumes of the candidate wastes from available literature and then projecting those volumes to the years 1975, 1980, 1985. This information was coupled with the earlier results on waste acceptability to determine the percentage of problem solution offered by the concept.

The method of waste characterization developed consists of the following steps:

1. Review the existing literature and obtain a list of hazardous industrial wastes considered as candidates for regional treatment and ultimate deposition underground in mined openings.

2. Compile and present the physical and hazardous properties for the wastes of concern.

3. Define and establish the criteria for "ideal" waste form for underground storage.

4. Develop a Hazard Index rating of the wastes to indicate their acceptability as candidates for underground storage without pretreatment.

5. Screen and divide the wastes according to their Hazard Index into those which require:

    A. No pretreatment
    B. Optional pretreatment
    C. Mandatory pretreatment

6. Compile and present the best waste treatment procedures available for rendering the wastes to their most ideal form for underground storage.

7. Further screen and divide the wastes into those which:

    A. Are acceptable for underground storage without pretreatment.
    B. Must be treated and whose treatment products are toxic, but acceptable for underground storage.
    C. Must be treated and whose treatment products are essentially nontoxic but acceptable for underground storage.
    D. Must be treated and whose treatment requires further study.
    E. Are unacceptable for underground storage in any form.

8. Define and explain any potential reactions that could occur between the stored wastes after they are in place in a mine.

9. Define and explain any potential reactions that could occur between the stored wastes and the receiving geological formations.

10. Assess the potential for migration of the wastes.

11. Compile projected volumes of the wastes that can be anticipated for the years 1975, 1980, and 1985.

A schematic diagram is presented in Figure 19 showing the methodology used for characterizing the wastes.

The following are examples of the waste characterization process utilizing Figure 19. The decisions resulting in the classification of the wastes in Tables 7 through 11, as discussed later in this section, are depicted for a representative waste from each Table. The examples also indicate whether storage restrictions are necessary due to chemical interaction or if a waste occurs in negligible volume. These examples are meant as a guide in the use of the diagram.

CADMIUM

1. Table 3 lists Cadmium as a candidate waste.
2. Appendix B-1 lists the physical, chemical, and hazardous properties of Cadmium.
3. Appendix B-2 rates Cadmium waste with a Hazard Index of 2.
4. This Hazard Index places Cadmium on Table 4, Hazard Index = 0-5 Containerization only.
5. Since no treatment is necessary, Cadmium was placed on Table 7, as acceptable for underground storage in containers without treatment.
6. Due to its acceptability, Cadmium was analyzed for chemical interaction with other wastes and with selected lithologies and found to be storable with any waste in any lithology.
7. The volume of Cadmium waste was then analyzed and found to be sufficient to warrant regional treatment.

ALDRIN

1. Table 3 lists Aldrin as a candidate waste.
2. Appendix B-1 lists the physical, chemical, and hazardous properties of Aldrin.
3. Appendix B-2 rates Aldrin waste with a Hazard Index of 9.
4. This Hazard Index places Aldrin on Table 5, Hazard Index = 6-9 Optional Treatment.

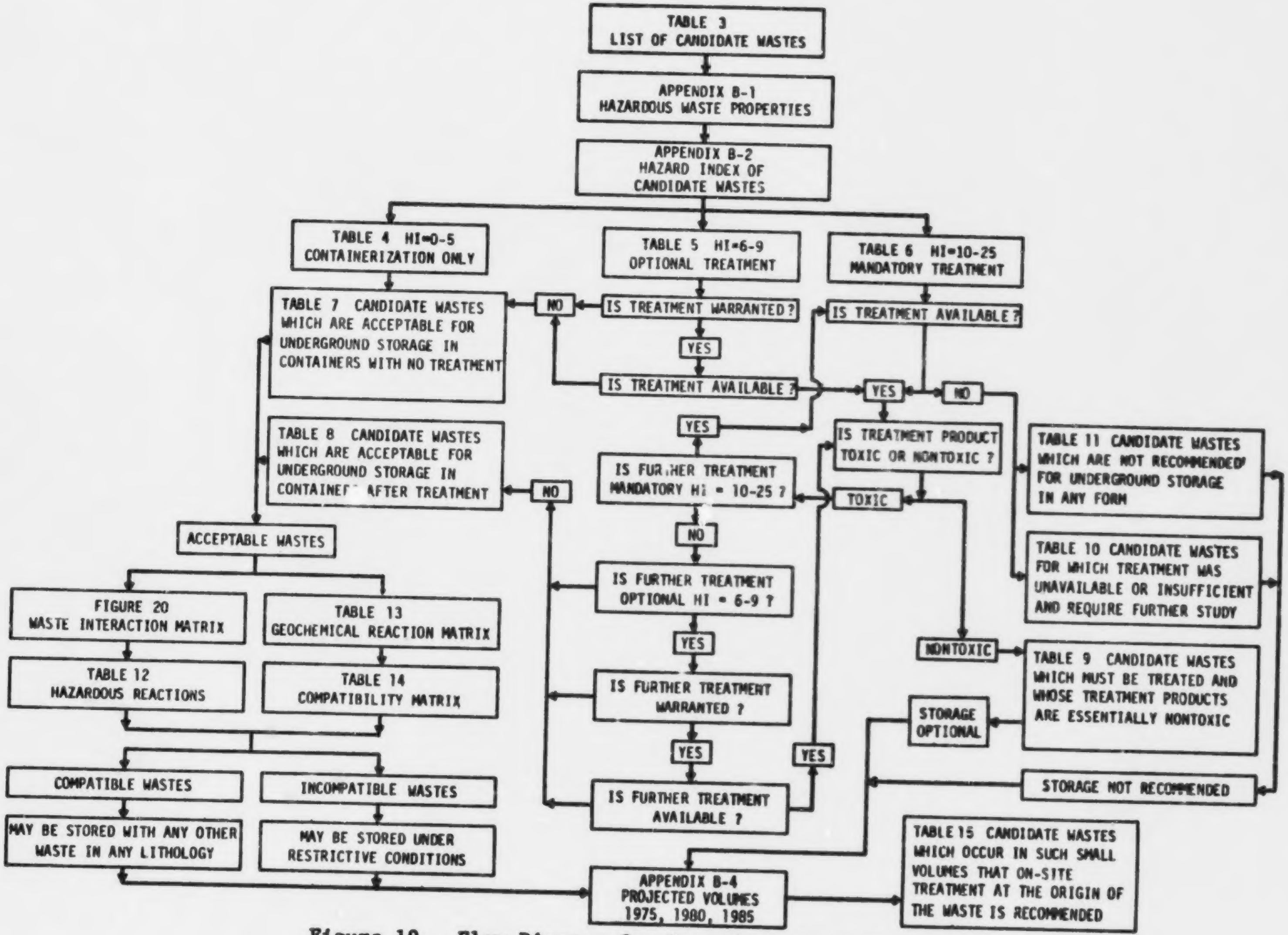


TABLE 3
LIST OF CANDIDATE WASTES
APPENDIX B-1
HAZARDOUS WASTE PROPERTIES
APPENDIX B-2
HAZARD INDEX OF CANDIDATE WASTES
TABLE 4 HI=0-5
CONTAINERIZATION ONLY
TABLE 5 HI=6-9
OPTIONAL TREATMENT
TABLE 6 HI=10-25
MANDATORY TREATMENT
TABLE 7 CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS WITH NO TREATMENT
NO
IS TREATMENT WARRANTED ?
YES
IS TREATMENT AVAILABLE ?
IS TREATMENT AVAILABLE ?
YES
NO
YES
TABLE 8 CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS AFTER TREATMENT
NO
IS FURTHER TREATMENT MANDATORY HI = 10-25 ?
IS TREATMENT PRODUCT TOXIC OR NONTOXIC ?
TOXIC
TABLE 11 CANDIDATE WASTES WHICH ARE NOT RECOMMENDED FOR UNDERGROUND STORAGE IN ANY FORM
NO
ACCEPTABLE WASTES
IS FURTHER TREATMENT OPTIONAL HI = 6-9 ?
TABLE 10 CANDIDATE WASTES FOR WHICH TREATMENT WAS UNAVAILABLE OR INSUFFICIENT AND REQUIRE FURTHER STUDY
FIGURE 20
WASTE INTERACTION MATRIX
TABLE 13
GEOCHEMICAL REACTION MATRIX
YES
NONTOXIC
TABLE 12
HAZARDOUS REACTIONS
TABLE 14
COMPATIBILITY MATRIX
IS FURTHER TREATMENT WARRANTED ?
TABLE 9 CANDIDATE WASTES WHICH MUST BE TREATED AND WHOSE TREATMENT PRODUCTS ARE ESSENTIALLY NONTOXIC
STORAGE OPTIONAL
YES
YES
COMPATIBLE WASTES
INCOMPATIBLE WASTES
IS FURTHER TREATMENT AVAILABLE ?
STORAGE NOT RECOMMENDED
MAY BE STORED WITH ANY OTHER WASTE IN ANY LITHOLOGY
MAY BE STORED UNDER RESTRICTIVE CONDITIONS
APPENDIX B-4
PROJECTED VOLUMES 1975, 1980, 1985
TABLE 15 CANDIDATE WASTES WHICH OCCUR IN SUCH SMALL VOLUMES THAT ON-SITE TREATMENT AT THE ORIGIN OF THE WASTE IS RECOMMENDED

Figure 19. Flow Diagram for Hazardous Waste Characterization.

5. The next decision in the screening process is whether the hazards presented by Aldrin warrant treatment. Since Aldrin is relatively safe at ambient conditions and its treatment would be costly, it was assumed that the risks of its untreated storage did not warrant treatment. Therefore, Aldrin was placed on Table 7 as acceptable for underground storage in containers without treatment.

6. Due to its acceptability, Aldrin was analyzed for chemical interaction with other wastes and with selected lithologies and found to be storable with any waste in any lithology.

7. The volume of Aldrin waste was analyzed and found to be sufficient to warrant regional treatment.

AMMONIUM CHROMATE

1. Table 3 lists Ammonium Chromate as a candidate waste.

2. Appendix B-1 lists the physical, chemical, and hazardous properties of Ammonium Chromate.

3. Appendix B-2 rates Ammonium Chromate waste with a Hazard Index of 21.

4. This Hazard Index places Ammonium Chromate on Table 6, Hazard Index = 10-25 Mandatory treatment.

5. Since treatment is mandatory, the remaining steps classify the treatment products of Ammonium Chromate. It was found that treatment was available and that the products of the first level of treatment were toxic with a Hazard Index of greater than ten. This meant that further treatment was mandatory. The products of the second level of treatment were also toxic but had a Hazard Index of 4 and therefore required no further treatment except volume reduction by filtration. The final product, Chromium Hydroxide and water, was then placed on Table 8, as acceptable for underground storage in containers after treatment.

6. Due to its acceptability, this treatment product was analyzed for chemical interaction with other wastes and with selected lithologies and found to be storable under restrictive conditions due to hazardous reactions with some other wastes.

7. The volume of Ammonium Chromate was then analyzed and found to be sufficient to warrant regional treatment.

Table 3. LIST OF CANDIDATE WASTES FOR UNDERGROUND STORAGE

ID. No.	Substance
8	Acrolein
13	Aldrin
21	Ammonium Chromate
22	Ammonium Dichromate
27	Ammonium Picrate, Dry
28	Ammonium Picrate, Wet
36	Antimony Pentafluoride
43	Antimony Trifluoride
50	Arsenic Trichloride
51	Arsenic Trioxide
55	Benzene Hexachloride (Lindane)
61,505	Boron Hydrides
66	Bromine Pentafluoride
80	Cacodylic Acid
81	Cadmium
83	Cadmium Chloride
84	Cadmium Cyanide
478	Cadmium Fluoride
479	Cadmium Nitrate
85	Cadmium Oxide
86	Cadmium Phosphate
480	Cadmium Potassium Cyanide
82	Cadmium, Powdered
481	Cadmium Sulfate
87	Calcium Arsenate
88	Calcium Arsenite
91	Calcium Cyanide
484	Chlordane
105	Chlorine
106	Chlorine Trifluoride & Chlorine Pentafluoride
114	Chromic Acid (Liquids, Chromium Trioxide)
490	Copper Acetoarsenite
517	Copper Acetylide
119	Copper Arsenate
518	Copper Chlorotetrazole
120	Copper Cyanide
128	Cuprous (Copper) Cyanide
129	Cyanides
136	DDD
137	DDT
491	Demeton
520	Detonators & Primers
521	Diazodinitrophenol
135	2,4-D (Dichlorophenoxyacetic Acid)
149	Dieldrin
160	Dimethyl Sulfate (Methyl Sulfate)
162	Dinitro Cresols
165	Dinitrotoluene
522	Dipentaerythritol Hexanitrate (DPEHN)
170	Endrin
200	Fluorine
287	GB (Non-persistent nerve gas)
523	Gelatinized Nitrocellulose (PNC)
525	Glycol Dinitrate (DDN)
526	Gold Fulminate
495	Guthion
496	Heptachlor
221	Hydrogen Sulfide
235	Lead Arsenate
236	Lead Arsenite
529	Lead Azide
239	Lead Cyanide
530	Lead 2,4 Dinitroresorcinate (LDNR)
531	Lead Styphnate
243	Lewisite
245	Magnesium Arsenite
500	Manganese Arsenate
532	Mannitol Hexanitrate
253	Mercuric Chloride
254	Mercuric Cyanide
503	Mercuric Diammonium Chloride
255	Mercuric Nitrate
256	Mercuric Sulfate
257	Mercury
258	Organic Mercury Compounds
533	Mercuric Fulminate
274	Methyl Parathion
293	Nickel Carbonyl
295	Nickel Cyanide
534	Nitrocellulose
306	Nitrogen Mustard

Table 3 (continued). LIST OF CANDIDATE WASTES FOR UNDERGROUND STORAGE

ID. No.	Substance
307	Nitroglycerin
321	Parathion
505	Pentaborane
322	Pentachlorophenol
319	Pentaerythritol Tetranitrate (PETN)
324	Perchloric Acid
326	Perchloryl Fluoride
338	Picric Acid
341	Potassium Arsenite
343	Potassium Chromate
344	Potassium Cyanide (solid)
345	Potassium Dichromate
536	Potassium Dinitrobenzfuroxan (KDNBF)
537	Silver Actylide
538	Silver Azide
370	Silver Cyanide
539	Silver Styphnate
540	Silver Tetrazene
541	Smokeless Gunpowder
376	Sodium Arsenate
377	Sodium Arsenite
382	Sodium Cacodylate
386	Sodium Chromate
387	Sodium Cyanide
379	Sodium Dichromate
543	Sulfur Mustard
418	TNT
422,107	Tear Gas (CN) (Chloroacetophenone)
423	Tear Gas, Irritant (CS)
542	Tetrazene
288	VX (Persistent Nerve Gas)
453	Zinc Arsenate
454	Zinc Arsenite
457	Zinc Cyanide

ACROLEIN

The analysis of Acrolein is similar to that of Ammonium Chromate. Due to its Hazard Index of 22, the treatment of Acrolein is mandatory. However, the treatment products of Acrolein are Carbon Dioxide and water which are nontoxic. Therefore, Acrolein was placed on Table 9 as having nontoxic treatment products. The remaining volume screening indicates that the waste volume of Acrolein is negligible and should be treated at its point of origin.

GOLD FULMINATE

Since information concerning Gold Fulminate is classified, its only known properties were its explosive and flammable hazards. These properties classified its treatment as mandatory. However, since no procedure was available, it was placed in Table 10 as requiring further study. The volume screening indicated that a negligible amount of Gold Fulminate waste could be expected and should be handled at its point of origin.

MERCURY

The process for Mercury is similar to the previous examples. Due to its Hazard Index of 10, the treatment of Mercury is mandatory. However, since Mercury is an element, there is no treatment for Mercury and little chance exists of one ever being developed. Therefore, Mercury was placed on Table 11 as being not recommended for storage in any form. Due to its unacceptability the only further screening performed was that of volume. It was found that Mercury would occur in volumes sufficient to warrant regional treatment, but its use in industry is declining. (Although Mercury wastes are not acceptable underground using the safety criteria of this study, it is possible that other storage alternatives will hold even greater environmental risk.)

The following discussions are presented to explain each characterization step in detail.

STEP 1 - CANDIDATE WASTES

Many wastes which occur from industrial processes present severe hazards to the environment. The properties of these wastes are such that normal industrial treatment may not render them safe for conventional disposal. A list of hazardous wastes presenting special problems was compiled from a previous study. Subsequent review of the methodology used in obtaining this list was found to be consistent with the objectives of this study. Therefore, this list of 115 candidate wastes was utilized as the data base for waste characterization. In the interest of consistency, the identification numbers previously assigned to the hazardous wastes were maintained throughout this study.

The investigators of this study are basically in agreement with the concept of national or regional treatment facilities as suggested by previous contractors. If such a treatment center were located in conjunction with a mine storage facility, then the hazardous wastes generated in a region could be handled at a centralized location. It is believed that this concept would greatly reduce the dangers to the environment presented by hazardous wastes.

The list of candidate wastes for underground storage is presented in Table 3. This list may require additions or deletions as subsequent information on waste-streams is generated.

STEP 2 - CANDIDATE WASTE PROPERTIES

Based on the pure-form approach, the physical, chemical, and hazardous properties of each candidate waste were compiled. This information, along with pertinent results of the characterization of each waste, is presented in Appendix B-1. The information in Appendix B-1 is meant to serve as a basis for rating the acceptability of each waste for underground storage. Although the pure-form approach provides more information than the waste-stream approach, significant voids in this data do exist. Examples of the types of information lacking are: melting points, boiling points, flammable and explosive limits, sublimation temperatures, solubilities, densities, handling precautions, toxicology, and, in some cases, chemical formulas. Since information concerning the properties of the hazardous constituents in waste streams would be essential to the efficient operation of a waste facility, further research in these areas is recommended. If, at some time in the future, the recommended information on waste streams per se is generated, the pure-form approach should be replaced by the waste-stream approach. This would necessitate the revision of some of the information contained in this section. However, the developed methodology of waste characterization would remain unchanged.

STEP 3 - IDEAL WASTE CRITERIA

In considering the factors controlling the storage of hazardous wastes in mined openings, the elimination of environmental hazards was of primary concern. To achieve this goal, a method of evaluating the acceptability of each waste was required. The methodology utilized was to define and establish criteria for an "ideal" waste form for underground storage and to compare each waste to the ideal. The criteria established for an "ideal" waste form are as follows:

1. Nonflammable.
2. Nonexplosive.

3. Nonvolatile (will not evolve flammable, explosive, or toxic gases when exposed to air, water, or heat).
4. Insoluble in water.
5. Nonreactive with other stored wastes or with the receiving geological formation(s).
6. In a form which requires the least amount of available mine space for storage.
7. Cohesive (will not create a dust).
8. Containerized.

These criteria apply strictly to a theoretical waste in its most acceptable form for underground storage.

The candidate wastes were evaluated on how closely they approached the ideal. It should be stressed that a particular waste need not meet all of the above criteria to be acceptable for underground storage. These criteria represent the greatest degree of protection to the environment. Each waste form presents its own particular degree of hazard and each hazard presents its own degree of acceptability. The correlation of these factors determines whether or not a waste is acceptable. The method used to evaluate the relationship of hazards versus acceptability is explained in Step 4.

STEP 4 - RATING OF HAZARDS

To represent the degree of hazard of each waste a numerical rating system was developed. The hazards associated with the wastes of concern were divided into six categories:

1. Flammable.
2. Explosive.
3. Evolve gases in air or water.
4. Evolve gases with heat.
5. Soluble in water.
6. Toxic.

These hazards represent those considered most significant in relation to approaching the "ideal" waste form for underground storage. Each category was assigned a range of numerical ratings according to its significance. The wastes are then rated within each category according to the severity of their hazards. The reasoning used in assigning the ratings is explained in the following discussion.

Category 1 - Flammable

The flammability hazards associated with each substance were considered of extreme importance. The storage of a highly flammable material would create a hazard too great for the safety and security of the mine during handling and storage or in the event of a mine fire. This rating system was designed to classify all those materials which presented significant flammability hazards as unacceptable for underground storage without previous treatment. Flammability hazards were assigned values of 0 through 7 according to their severity.

Materials Given A Flammability Rating Of 7 Include--

1. Highly flammable and/or explosive gases, liquids, or solids.
2. Materials which evolve highly flammable, explosive, and/or reactive gases upon contact with air, water, or slight heat.
3. Materials which are highly reactive and will ignite, explode, or react to form highly flammable or explosive substances on contact with materials which may be found or stored in the mine.
4. Materials forming flammable or explosive dusts or mists when dispersed in air.
5. Materials spontaneously flammable or explosive in air or water.

An example of a waste presenting a severe flammability hazard is Acrolein.

Materials Given Flammability Ratings Of 4 Through 6 Include--

1. Moderately flammable and/or explosive gases, liquids, or solids.
2. Materials which evolve moderately flammable, explosive, and/or reactive gases upon contact with air, water, or heat.
3. Materials which are less reactive and may ignite, explode, or react to form flammable or explosive substances on contact with materials which may be found or stored in the mine.

An example of a waste presenting a moderate flammability hazard is Potassium Chromate which is a good oxidizer.

Materials Given Flammability Ratings Of 1 Through 3 Include--

1. Slightly flammable and/or explosive gases, liquids, or solids.
2. Materials which evolve slightly flammable, explosive, and/or reactive gases upon contact with air, water, or heat.
3. Materials which are weakly reactive and could ignite, explode or react to form flammable or explosive substances on contact with other materials which may be found or stored in the mine.
4. Materials which are or form flammable, explosive, and/or reactive substances only under special conditions.

An example of a waste presenting a slight flammability hazard is Aldrin which is a pesticide that may or may not be flammable depending upon the solvent used in formulation.

Materials given a flammability rating of 0 presented no significant flammability hazard.

Category 2 - Explosive

The explosive hazards associated with each waste were considered of extreme importance. The handling and storage of highly explosive wastes in an underground facility would present too great a hazard to be accepted. Many of the explosive wastes are extremely sensitive to the slightest mechanical, electrical, or thermal shock and are much more powerful than common explosives used in mining operations. For the purposes of this rating system, an explosive waste was also assumed to be flammable and to evolve gases with heat, therefore, a substance rated here also received a rating in Category 1 and Category 4. This rating system was designed to classify all those materials which presented significant explosive hazards as unacceptable for underground storage without previous treatment. Explosive hazards were assigned values of 0 through 7 according to their severity.

Materials Given An Explosive Rating Of 7 Include--

1. Highly explosive and/or violently reactive gases, liquids, or solids.
2. Materials which evolve highly explosive and/or violently reactive gases upon contact with air, water, or slight heat.
3. Materials which are highly reactive and will explode, react violently, or react to form explosive or violently reactive substances on contact with materials which may be found or stored in the mine.
4. Materials forming explosive dusts or mists when dispersed in air.
5. Materials spontaneously explosive in air or water.

An example of a waste presenting a severe explosive hazard is Diazodinitrophenol (DDNP).

Materials Given Explosive Ratings Of 4 Through 6 Include--

1. Moderately explosive and/or reactive gases, liquids, or solids.
2. Materials which evolve moderately explosive and/or reactive gases upon contact with air, water, or heat.
3. Materials which are less reactive and may explode, react violently, or react to form explosive or violently reactive substances on contact with materials which may be found or stored in the mine.

An example of a waste presenting a moderate explosive hazard is Cadmium Nitrate which is a good oxidizer.

Materials Given Explosive Ratings Of 1 Through 3 Include--

1. Explosive materials relatively insensitive to flame, spark,

or impact.
2. Materials which evolve weakly explosive gases upon contact with air, water or heat.
3. Materials which are weakly reactive and could explode or react to form explosive substances on contact with materials which could be found or stored in the mine.
4. Materials which are explosive or form explosive substances only under special conditions.

An example of a waste presenting a slight explosive hazard is Chlordane which is a pesticide that may or may not evolve explosive hydrogen gas if heated to decomposition without ignition.

Materials given an explosive rating of 0 presented no significant explosive hazard.

Category 3 - Evolve Gas In Air Or Water

This category rates the degree of hazard associated with substances which evolve flammable, explosive, or toxic gases in air or water. In the event of a mine flood or accidental container rupture, the storage of these materials would present severe hazards to the safety of the facility. Although these hazards are considered highly significant, this rating system was not designed to classify those wastes given the maximum rating as unacceptable for underground storage without previous treatment strictly on the basis of this category. If the gas evolved is strictly toxic and not flammable or explosive, the hazard rating under this category is also qualified by a rating in Category 6 - Toxic. However, if the gas evolved is flammable or explosive or both, the hazard rating under this category is also qualified by a rating in Categories 1 and 2. This means that a waste with a rating in this category will be rated in at least one other category as well. For this reason, the hazard ratings in this category were valued from 0 through 3. A hazard rating of 3 indicates a severe hazard, a rating of 2 a moderate hazard, and a rating of 1 a slight hazard.

The ratings under Category 3 are based upon specific properties of a material which are:

1. The vapor pressure at ambient conditions.
2. The flammable and/or explosive limits in air.
3. The reactivity with air, water, or oxidizable materials at ambient conditions.
4. The estimated 24 hour TLV in air.
5. The recommended provisional limit in air.

Materials Given A Hazard Rating Of 3 Include--

1. Materials whose vapors are highly flammable, explosive, toxic, and/or reactive and have high vapor pressures at ambient conditions.

2. Materials which react upon contact with air or water to evolve flammable and/or explosive gases in concentrations exceeding their lower flammable or explosive limits in air. If the data necessary to classify a material under this criteria was not available, the worst case was assumed and the material was given a rating of 3.
3. Materials which react upon contact with air or water to evolve toxic gases in concentrations exceeding their 24 hour TLV in air. If the data necessary to classify a material under this criteria was not available, the worst case was assumed and the material was given a rating of 3.
4. Materials which react upon contact with air or water to evolve highly reactive gases which will ignite, explode, or react to form flammable, explosive, or toxic substances on contact with materials which may be found or stored in the mine.
5. Gases which are highly flammable, explosive, toxic, and/or reactive.

An example of a waste presenting a severe hazard of evolving a hazardous gas in air or water is Potassium Cyanide which will evolve flammable, explosive, and toxic Hydrogen Cyanide gas on contact with air.

Materials Given A Hazard Rating Of 2 Include--

1. Materials whose vapors are flammable, explosive, toxic, and/or reactive and have moderate vapor pressures in ambient air.
2. Materials which react upon contact with air or water to evolve flammable or explosive gases in concentrations less than their lower flammable or explosive limits in air.
3. Materials which react upon contact with air or water to evolve toxic gases in concentrations greater than their recommended provisional limit but less than their 24 hour TLV in air.
4. Materials which react upon contact with air or water to evolve moderately reactive gases which may ignite, explode, or react to form flammable, explosive, or toxic substances on contact with materials which may be found or stored in the mine.
5. Gases which are moderately flammable, explosive, toxic, and/or reactive.

An example of a waste presenting a moderate hazard is Mercuric Sulfate which evolves toxic fumes of Mercury in air but has a moderate vapor pressure.

Materials Given A Hazard Rating Of 1 Include--

1. Materials whose vapors are flammable, explosive, toxic, and/or reactive and have low vapor pressures in ambient air.
2. Materials which are weakly reactive upon contact with air or water and may evolve flammable and/or explosive gases in concentrations below their lower flammable and/or explosive limits in air.

3. Materials which are weakly reactive upon contact with air or water to evolve toxic gases in concentrations below their recommended provisional limit in air.
4. Materials which react upon contact with air or water to evolve weakly reactive gases which may ignite, explode, or react to form flammable, explosive, or toxic substances on contact with materials which may be found or stored in the mine.
5. Gases which are weakly flammable explosive, toxic, and/or reactive.

An example of a waste presenting a slight hazard is Mercuric Chloride.

Materials given a hazard rating of 0 presented no significant hazard of evolving gases in air or water.

Category 4 - Evolve Gas With Heat

If materials stored in a mine evolved flammable, explosive, or toxic gases when subjected to heat, the hazards involved in a mine fire would be significantly increased. If a flammable and/or explosive gas were evolved, a fire might conceivably spread throughout the mine in a relatively short period of time. If toxic gases were evolved, extinguishing a mine fire would become much more difficult and hazardous. With this in mind, the hazard ratings under this category were based upon the following criteria:

1. The temperatures which would be attained in a mine fire.
2. The boiling point of a substance.
3. The temperature of decomposition of a substance.
4. The vapor pressure of a substance.
5. The flammable and/or explosive limits of a substance in air.
6. The estimated 24 hour TLV of a toxic substance in air.
7. The recommended provisional limit of a toxic substance in air.

The temperatures attained in a mine fire are controlled by the type of fuel, the availability of fuel, and the availability of oxygen. Depending upon the combinations of these factors, temperatures ranging from a few hundred degrees centigrade to well over one thousand degrees centigrade may be attained. Due to the complexities and uncertainties of this situation, temperature ranges were selected as a basis for ratings in this category. The selection of these temperature ranges was based upon two assumptions:

1. The probability of a mine fire attaining lower temperature ranges is greater than that of attaining higher temperature ranges due to the types of fuel available.
2. A mine fire will pass through a low temperature range before reaching a high temperature range.

Therefore, a substance which will evolve a hazardous gas in a low temperature fire is classified as more hazardous than a substance which requires a high temperature fire to evolve a hazardous gas.

Materials which evolve hazardous gases between 40° and 500°C (below 40°C rated in Category 3 - Evolve Gas In Air Or Water) were rated as severe hazards, between 500° and 1,000°C as moderate hazards, and over 1,000°C as slight hazards.

The hazard ratings in this category were valued from 0 through 3 for the same reasons of qualification as explained in Category 3. A hazard rating of 3 indicates a severe hazard, a 2 rating indicates a moderate hazard, and a 1 rating indicates a slight hazard.

Materials Given A Hazard Rating Of 3 (Category 4) Include--

1. Materials whose vapors are flammable, explosive, toxic, and/or reactive and have boiling points between 40° and 500°C.
2. Materials which decompose at temperatures between 40° and 500°C evolving flammable and/or explosive gases in concentrations exceeding their lower flammable and/or explosive limits in air.
3. Materials which decompose at temperatures between 40° and 500°C evolving toxic gases in concentrations exceeding their recommended 24 hour TLV in air.
4. Materials which decompose at temperatures between 40° and 500°C evolving gases which are reactive and will ignite, explode, or react to form flammable, explosive, or toxic substances on contact with other materials which may be found or stored in the mine.

An example of a waste presenting a severe hazard is Ammonium Picrate which autoignites at 423°C, evolving toxic fumes of nitrous oxides.

Materials Given A Hazard Rating Of 2 Include--

1. Materials whose vapors are flammable, explosive, toxic, and/or reactive and have boiling points between 500° and 1,000°C.
2. Materials which decompose at temperatures between 500° and 1,000°C evolving flammable and/or explosive gases in concentrations below their lower flammable and/or explosive limits in air.
3. Materials which decompose at temperatures between 500° and 1,000°C evolving toxic gases in concentrations greater than their recommended provisional limit but less than their 24 hour TLV in air.
4. Materials which decompose at temperatures between 500° and 1,000°C evolving gases which are reactive and may ignite, explode, or react to form flammable, explosive, or toxic substances on contact with other materials which may be found or stored in the mine.

An example of a waste presenting a moderate hazard is Cadmium.

Materials Given A Hazard Rating Of 1 Include--

1. Materials whose vapors are flammable, explosive, toxic, and/or reactive and have boiling points above 1,000°C.
2. Materials which decompose at temperatures above 1,000°C evolving flammable and/or explosive gases in concentrations below their lower flammable or explosive limits in air.
3. Materials which decompose at temperatures above 1,000°C evolving toxic gases in concentrations below their recommended provisional limit in air.
4. Materials which decompose at temperatures above 1,000°C evolving gases which are reactive and may ignite, explode, or react to form flammable, explosive, or toxic substances on contact with other materials which may be found or stored in the mine.

An example of a waste presenting a slight hazard is Lead Arsenite.

Materials given a hazard rating of 0 presented no significant hazard of evolving gases with heat.

Category 5 - Soluble In Water

The solubility of a material in water was considered as a hazard for two main reasons:

1. A soluble material presented a much greater potential for migration out of the mine environment.
2. A soluble material would be much more chemically reactive with the lithology or with other materials stored in the mine.

Although these hazards are significant, they do not present as great a short term hazard to the environment as do Categories 1 through 4; hence, the ratings in this category were given a value of 0 through 2. A rating of 2 indicates that a material is soluble above its recommended provisional limit* in water and presents a severe hazard. A rating of 1 indicates that a material is soluble below its recommended provisional limit in water and presents a moderate to slight hazard. A rating of 0 indicates a material is insoluble in water and presents no significant hazard. It should be noted that solubility in water can be affected by pH, temperature, agitation, and other factors. For the purposes of this rating, it was assumed that the water was at neutral pH, cool, and slow moving to stagnant.

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*Equal to drinking water standard (see definitions).

Category 6 - Toxic

A toxic material has three principal methods by which it may enter the human body:

1. Ingestion
2. Inhalation
3. Absorption through skin

For simplicity, each of these methods of entry was considered to be equally significant. Since this rating system was designed to indicate the degree of hazard, a material toxic by all three methods of entry was assumed to constitute a greater threat to safety than one toxic by only two methods, and given a rating of 3 to indicate a severe hazard. A material which was toxic by only two of the three methods was considered a moderate hazard and was given a rating of 2. A material which was toxic by only one method was considered the least hazardous and given a rating of 1. A nontoxic waste was given a rating of 0. Although the hazards associated with a material due to its toxicity are significant, this rating system was not designed to classify a material as unacceptable underground without pretreatment strictly on the basis of its toxicity.

After a waste is rated in each of the six categories, the sum of the individual ratings make up a waste's total hazard or Hazard Index (H.I.). This number indicates the acceptability of a waste for underground storage without previous treatment. The lower the Hazard Index the more acceptable a waste becomes.

Appendix B-2, Hazard Index of Candidate Wastes, presents the individual ratings of each waste and its total hazard or Hazard Index. If data concerning the hazards of a particular waste was not available, rating the waste became a judgemental decision. In the event such a decision was necessary, the worst case was assumed. Although an attempt was made to make this rating system as objective as possible to aid in future use, a certain amount of subjectivity was unavoidable due to a lack of information. However, when sufficient data on wastes and waste streams becomes available, such subjective decisions will no longer be necessary.

STEP 5 - FIRST SCREENING

The purpose of the first screening was to divide the wastes into groups according to their Hazard Index. The results of this screening are presented in three tables:

1. Table 4, H.I. = 0-5, CONTAINERIZATION ONLY, lists the wastes which require no previous treatment, other than containerization, to be acceptable for underground storage.

2. Table 5, H.I. = 6-9, OPTIONAL TREATMENT, lists wastes which are acceptable for underground storage in containers but may warrant treatment to a less hazardous form if the risks presented by pure-form storage are considered too great.
3. Table 6, H.I. = 10-25, MANDATORY TREATMENT, lists the wastes which, based upon the criteria adopted for this study, are unacceptable for underground storage in containers without previous treatment.

Table 4. HAZARD INDEX 0-5 CONTAINERIZATION ONLY. ACCEPTABLE FOR UNDERGROUND STORAGE.

ID. No.	Substance	ID. No.	Substance
81	Cadmium, as a solid	235	Lead Arsenate
83	Cadmium Chloride	236	Lead Arsenite
478	Cadmium Fluoride	245	Magnesium Arsenite
85	Cadmium Oxide	500	Manganese Arsenate
86	Cadmium Phosphate	341	Potassium Arsenite
481	Cadmium Sulfate	376	Sodium Arsenate
87	Calcium Arsenate	377	Sodium Arsenite
88	Calcium Arsenite	453	Zinc Arsenate
119	Copper Arsenate	454	Zinc Arsenite

Table 5. HAZARD INDEX 6-9 OPTIONAL TREATMENT. ACCEPTABLE FOR UNDERGROUND STORAGE.

ID. No.	Substance	ID. No.	Substance
13	Aldrin	491	Demeton
51	Arsenic Trioxide	149	Dieldrin
55	Benzene Hexachloride	170	Endrin
80	Cacodylic Acid	495	Guthion
490	Copper Acetoarsenite	496	Heptachlor
135	2, 4-D	322	Pentachlorophenol
136	DDD	382	Sodium Cacodylate
137	DDT		

Table 6. HAZARD INDEX 10-25 MANDATORY TREATMENT. NOT ACCEPTABLE FOR UNDERGROUND STORAGE WITHOUT TREATMENT.

ID. No.	Substance	ID. No.	Substance
8	Acrolein	28	Ammonium Picrate, Wet
21	Ammonium Chromate	36	Antimony Pentafluoride
22	Ammonium Dichromate	43	Antimony Trifluoride
27	Ammonium Picrate, Dry	50	Arsenic Trichloride

Table 6 (continued). HAZARD INDEX 10-25 MANDATORY TREATMENT. NOT ACCEPTABLE FOR UNDERGROUND STORAGE WITHOUT TREATMENT.

ID. No.	Substance
61,505	Boron Hydrides
66	Bromine Pentafluoride
82	Cadmium, Powdered
84	Cadmium Cyanide
479	Cadmium Nitrate
480	Cadmium Potassium Cyanide
91	Calcium Cyanide
484	Chlordane
105	Chlorine
106	Chlorine Trifluoride, Chlorine Pentafluoride
114	Chromic Acid
517	Copper Acetylide
518	Copper Chlorotetrazole
120	Copper Cyanide
128	Cuprous (Copper) Cyanide
129	Cyanides
520	Detonators & Primers
521	Diazodinitrophenol (DDNP)
160	Dimethyl Sulfate (Methyl Sulfate)
162	Dinitro Cresols
165	Dinitrotoluene (DNT)
522	Dipentaerythritol Hexanitrate (DPEHN)
200	Fluorine
287	GB (Nonpersistent nerve gas)
523	Gelatinized Nitrocellulose (PNC)
525	Glycol Dinitrate (DDN)
526	Gold Fulminate
221	Hydrogen Sulfide
529	Lead Azide
239	Lead Cyanide
530	Lead 2, 4 Dinitroresorcinate (LDNR)
531	Lead Styphnate
243	Lewisite
532	Mannitol Hexanitrate
253	Mercuric Chloride
254	Mercuric Cyanide
503	Mercuric Diammonium Chloride
533	Mercuric Fulminate
255	Mercuric Nitrate
256	Mercuric Sulfate
257	Mercury
258	Organic Mercury Compounds
274	Methyl Parathion
293	Nickel Carbonyl
295	Nickel Cyanide
534	Nitrocellulose
306	Nitrogen Mustard
307	Nitroglycerin
321	Parathion
505	Pentaborane
319	Pentaerythritol Tetranitrate (PETN)
324	Perchloric Acid (72% Strength)
326	Perchloryl Fluoride
338	Picric Acid
343	Potassium Chromate
344	Potassium Cyanide
345	Potassium Dichromate
536	Potassium Dinitrobenzfuroxan (KDNBF)
537	Silver Acetylide
538	Silver Azide
370	Silver Cyanide
539	Silver Styphnate
540	Silver Tetrazene
541	Smokeless Gunpowder
386	Sodium Chromate
387	Sodium Cyanide
379	Sodium Dichromate
543	Sulphur Mustard
418	TNT
107,422	Tear Gas (CN) (Chloroacetophenone)
423	Tear Gas, Irritant (CS)
542	Tetrazene
288	VX (Persistent Nerve Gas)
457	Zinc Cyanide

STEP 6 - TREATMENT PROCEDURES

Once the wastes had been screened according to the severity of their hazards, an attempt was made to compile treatment procedures for the candidate wastes. The purpose of these procedures was to reduce the wastes to the level exhibiting the least potential danger to the environment. In Appendix B-3, this level is presented as the "Ideal Form". Although the waste form attained at this level presented the least hazard, it was not the only form acceptable for underground storage. Since the basis of acceptability was a Hazard Index of less than ten, many of the wastes were acceptable before or during treatment without being in their "Ideal Form". This level is presented as "Acceptable Form" in Appendix B-3 and represents the minimum mandatory level of treatment required for a waste to be acceptable in an underground environment. The point at which this level of treatment is reached is indicated by the heavy line on each form in Appendix B-3. Since some hazards are still present in the "Acceptable Form" and treatment to the "Ideal Form" may be uneconomical, a cost-benefit analysis to determine the proper level of treatment prior to storage would be required. However, since economic evaluations were not within the scope of this study, it was assumed that the "Acceptable Form" would be placed underground. Subsequent treatment towards the "Ideal Form" was considered as optional.

It should be noted that volume reduction by filtration was considered as a mandatory treatment step, except when soluble, toxic compounds were present, to provide for the most efficient use of available mine space. In addition, two pages have been included in Appendix B-3 for some explosive wastes to allow for their treatment as obsolete munitions. Since munitions require primers as well as explosive charges, they may contain toxic materials not found in explosive manufacturing wastes. In accordance with the "worst case" philosophy, these materials were assumed to be present and treatment procedures were postulated accordingly.

STEP 7 - SECOND SCREENING

The purpose of the next screening process was to obtain a list of all possible acceptable waste forms for storage whether they be treated or untreated. This screening was based upon the results of the treatment of the wastes. The information generated by this screening is presented in the following tables:

1. Table 7, CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS WITH NO TREATMENT, lists all the wastes of concern with a Hazard Index of less than ten.
2. Table 8, CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS AFTER TREATMENT, lists all the wastes of concern which must be treated and whose treatment products are toxic, but acceptable for underground storage.

3. Table 9, CANDIDATE WASTES WHICH MUST BE TREATED AND WHOSE TREATMENT PRODUCTS ARE ESSENTIALLY NONTOXIC. UNDERGROUND STORAGE OF PRODUCTS IS OPTIONAL, lists the wastes which must be treated and whose treatment products are essentially nontoxic, but may present a risk to the environment if disposed of freely. A material such as salt (sodium chloride) is basically nontoxic, but would constitute a threat to the environment if it was disposed of in concentrated form with no control. The underground storage of such materials is acceptable, but may not constitute the best use of available mine space and is, therefore, considered optional.
4. Table 10, CANDIDATE WASTES FOR WHICH TREATMENT WAS UNAVAILABLE OR INSUFFICIENT AND REQUIRE FURTHER STUDY, lists all the wastes of concern which must be treated, but which were not acceptable for storage utilizing current treatment procedures. These wastes might be acceptable at a later date if treatment procedures can be developed or improved, or if different risk values are assigned. It is a recommendation of this study that research in this area be carried out.

5. Table 11, CANDIDATE WASTES WHICH ARE NOT RECOMMENDED FOR UNDERGROUND STORAGE IN ANY FORM, lists the wastes which are not acceptable for underground storage in either their treated or untreated form.

Table 7. CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS WITH NO TREATMENT.

ID. No.	Substance	ID. No.	Substance
13	Aldrin	491	Demeton
51	Arsenic Trioxide	149	Dieldrin
55	Benzene Hexachloride	170	Endrin
80	Cacodylic Acid	495	Guthion
81	Cadmium (as a solid)	496	Heptachlor
83	Cadmium Chloride	235	Lead Arsenate
478	Cadmium Fluoride	236	Lead Arsenite
85	Cadmium Oxide	245	Magnesium Arsenite
86	Cadmium Phosphate	500	Manganese Arsenate
481	Cadmium Sulfate	322	Pentachlorophenol
87	Calcium Arsenate	341	Potassium Arsenite
88	Calcium Arsenite	376	Sodium Arsenate
490	Copper Acetoarsenite	377	Sodium Arsenite
119	Copper Arsenate	382	Sodium Cacodylate
135	2, 4-D	453	Zinc Arsenate
136	DDD	454	Zinc Arsenite
137	DDT		

The treatment procedures for the wastes named in this table are presented on pages 325 through 357 of Appendix B-3, WASTE TREATMENT PROCEDURES.

Table 8. CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS AFTER TREATMENT.

ID. No.	Substance	ID. No.	Substance
21	Ammonium Chromate	529	Lead Azide
22	Ammonium Dichromate	239	Lead Cyanide
27	Ammonium Picrate, Dry (as munitions)	530	Lead 2, 4 Dinitroresorcinate (LDNR)
28	Ammonium Picrate, Wet (as munitions)	531	Lead Styphnate
36	Antimony Pentafluoride	243	Lewisite
43	Antimony Trifluoride	532	Mannitol Hexanitrate (as munitions)
50	Arsenic Trichloride	533	Mercuric Fulminate (as munitions)
82	Cadmium, Powdered	295	Nickel Cyanide
84	Cadmium Cyanide	307	Nitroglycerin (as munitions)
479	Cadmium Nitrate	319	Pentaerythritol Tetranitrate (PETN) (as munitions)
480	Cadmium Potassium Cyanide	338	Picric Acid (as munitions)
114	Chromic Acid	343	Potassium Chromate
517	Copper Acetylide	345	Potassium Dichromate
518	Copper Chlorotetrazole	536	Potassium Dinitrobenzfuroxan (KDNBF) (as munitions)
120	Copper Cyanide	370	Silver Cyanides
128	Cuprous (Copper) Cyanide	541	Smokeless Gunpowder (as munitions)
129	Cyanides	386	Sodium Chromate
520	Detonators & Primers	379	Sodium Dichromate
521	Diazopinitrophenol (DDNP) (as munitions)	418	TNT (as munitions)
165	Dinitrotoluene (DNT) (as munitions)	542	Tetrazene (as munitions)
522	Dipentaerythritol Hexanitrate (DPEHN) (as munitions)		
200	Fluorine		
287	GB (Nonpersistent Nerve gas)		
523	Gelantinized Nitrocellulose (PNC) (as munitions)		

The treatment procedures for the wastes named in this table are presented on pages 359 through 404, of Appendix B-3, WASTE TREATMENT PROCEDURES.

Table 9. CANDIDATE WASTES WHICH MUST BE TREATED AND WHOSE TREATMENT PRODUCTS ARE ESSENTIALLY NONTOXIC. UNDERGROUND STORAGE OF PRODUCTS IS OPTIONAL.

ID. No.	Substance
8	Acrolein
27	Ammonium Picrate, Dry (Nonmunitions)
28	Ammonium Picrate, Wet (Nonmunitions)
61,505	Boron Hydrides
91	Calcium Cyanide
484	Chlordane
105	Chlorine
106	Chlorine Trifluoride and Chlorine Pentafluoride
521	Diazodinitrophenol (DDNP) (Nonmunitions)
160	Dimethyl Sulfate (Methyl Sulfate)
162	Dinitro Cresols (DNOC)
165	Dinitrotoluene (DNT) (Nonmunitions)
522	Dipentaerythritol Hexanitrate (DPEHN) (Nonmunitions)
523	Gelatinized Nitrocellulose (PNC) (Nonmunitions)
525	Glycol Dinitrate (DDN)
221	Hydrogen Sulfide
532	Mannitol Hexanitrate (Nonmunitions)
274	Methyl Parathion
293	Nickel Carbonyl
534	Nitrocellulose (Munitions and Nonmunitions)
306	Nitrogen Mustard
307	Nitroglycerin (Nonmunitions)
321	Parathion
505	Pentaborane
319	Pentaerythritol Tetranitrate (PETN) (Nonmunitions)
324	Perchloric Acid (72% strength)
326	Perchloryl Fluoride
338	Picric Acid (Nonmunitions)
344	Potassium Cyanide
536	Potassium Dinitrobenzfuxoran (Nonmunitions)
541	Smokeless Gunpowder (Nonmunitions)
387	Sodium Cyanide
543	Sulphur Mustard
418	TNT (Nonmunitions)
107,422	Tear Gas (CN) (Chloroacetophenone)
423	Tear Gas, Irritant (CS)
542	Tetrazene
288	VX (Persistent Nerve Gas)
457	Zinc Cyanide

The treatment procedures for the wastes named on this table are presented on pages 406 through 444, of Appendix B-3, WASTE TREATMENT PROCEDURES.

Table 10. CANDIDATE WASTES FOR WHICH TREATMENT WAS UNAVAILABLE OR INSUFFICIENT AND REQUIRE FURTHER STUDY

ID. No.	Substance
526	Gold Fulminate
537	Silver Acetylide
538	Silver Azide
539	Silver Styphnate
540	Silver Tetrazene

The treatment procedures for the wastes named in Table 10 are presented on pages 446 through 454, of Appendix B-3, WASTE TREATMENT PROCEDURES.

Table 11. CANDIDATE WASTES WHICH ARE NOT RECOMMENDED FOR UNDERGROUND STORAGE IN ANY FORM.

ID. No.	Substance	ID. No.	Substance
66	Bromine Pentafluoride	255	Mercuric Nitrate
253	Mercuric Chloride	256	Mercuric Sulfate
254	Mercuric Cyanide	257	Mercury (Pure form or as treatment product)
503	Mercuric Diammonium Chloride	258	Organic Mercury Compounds
533	Mercuric Fulminate (Nonmunitions)		

The treatment procedures for the wastes named in this table are presented on pages 456 through 464, of Appendix B-3, WASTE TREATMENT PROCEDURES.

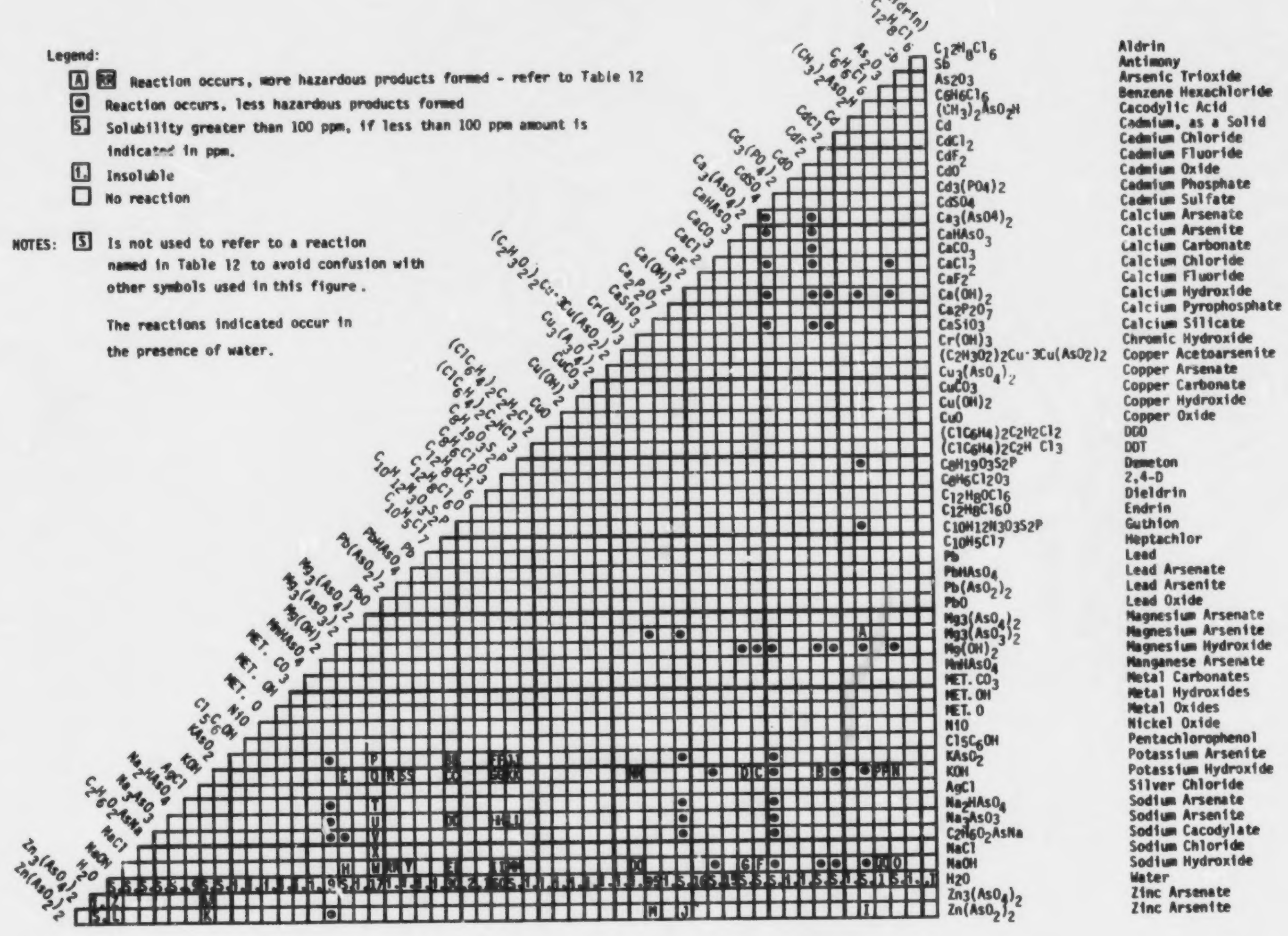
STEP 8 - WASTE INTERACTION AND COMPATIBILITY

Once a waste has been placed underground, the possibility of environmentally hazardous compounds being formed by chemical reactions among the stored wastes must be assessed. It was assumed that, in the event of a mine flood, the containers would rupture allowing the wastes to go into solution. Although this situation could be prevented by proper treatment and containerization, the "worst case" philosophy was employed. Under these conditions, the number of potential chemical reactions is staggering. Due to the enormous number of possible reactions, consideration of only the immediate or first level reactions was within the scope of this study. However, further research in this area is recommended.

In an attempt to evaluate the types of reactions which might occur, a waste interaction matrix utilizing the "Acceptable Form" was developed and is presented in Figure 20. The reactions in this figure are described as hazardous and nonhazardous. A hazardous reaction is one in which either of the following might occur:

1. The potential for migration of a waste is increased by the formation of a more soluble toxic compound.
2. Any new substances are formed which present greater hazards to the environment than the original substances.

In a nonhazardous reaction the reverse of the above is true. The hazardous reactions which may occur are explained in Table 12, Pages 109 through 113.



Legend:

- A ▨ Reaction occurs, more hazardous products formed - refer to Table 12
- ● Reaction occurs, less hazardous products formed
- S Solubility greater than 100 ppm, if less than 100 ppm amount is indicated in ppm.
- I Insoluble
- ☐ No reaction

NOTES: S Is not used to refer to a reaction named in Table 12 to avoid confusion with other symbols used in this figure.

The reactions indicated occur in the presence of water.

Aldrin
Antimony
Arsenic Trioxide
Benzene Hexachloride
Cacodylic Acid
Cadmium, as a Solid
Cadmium Chloride
Cadmium Fluoride
Cadmium Oxide
Cadmium Phosphate
Cadmium Sulfate
Calcium Arsenate
Calcium Arsenite
Calcium Carbonate
Calcium Chloride
Calcium Fluoride
Calcium Hydroxide
Calcium Pyrophosphate
Calcium Silicate
Chromic Hydroxide
Copper Acetoarsenite
Copper Arsenate
Copper Carbonate
Copper Hydroxide
Copper Oxide
DDD
DDT
Demeton
2,4-D
Dieldrin
Endrin
Guthion
Heptachlor
Lead
Lead Arsenate
Lead Arsenite
Lead Oxide
Magnesium Arsenate
Magnesium Arsenite
Magnesium Hydroxide
Manganese Arsenate
Metal Carbonates
Metal Hydroxides
Metal Oxides
Nickel Oxide
Pentachlorophenol
Potassium Arsenite
Potassium Hydroxide
Silver Chloride
Sodium Arsenate
Sodium Arsenite
Sodium Cacodylate
Sodium Chloride
Sodium Hydroxide
Water
Zinc Arsenate
Zinc Arsenite

Figure 20. Waste Interaction Matrix

Table 12. HAZARDOUS REACTIONS

Reaction	Explanation
Reaction A Magnesium Arsenite with Cacodylic Acid Reaction I Zinc Arsenite with Cacodylic Acid	The arsenites can react with cacodylic acid to form the cacodylate and arsenic trioxide. The greatest hazard associated with allowing these reactions to occur is that arsenic trioxide is formed. This compound has been given a hazard index of 7 (Appendix B-2) which classifies it as being optionally acceptable underground in its pure form. The main reasons for its optional acceptability are that arsenic trioxide sublimes at 193°C and is soluble in water.
Reaction B Potassium Hydroxide with Cadmium Fluoride Reaction C Potassium Hydroxide with Calcium Arsenate Reaction D Potassium Hydroxide with Calcium Arsenite Reaction E Potassium Hydroxide with Magnesium Arsenite Reaction K Potassium Hydroxide with Zinc Arsenite Reaction N Potassium Hydroxide with Arsenic Trioxide Reaction Q Potassium Hydroxide with Lead Oxide Reaction R Potassium Hydroxide with Lead Arsenite Reaction AA Potassium Hydroxide with Zinc Arsenate Reaction CC Potassium Hydroxide with Guthion	The only hazards associated with the potassium hydroxide reactions is that the resulting compounds of potassium are toxic, and are more soluble in water than the original compounds. Because of the increased solubility, there is a greater potential for migration from the mine or for further reaction with other substances. These compounds, however, would still be acceptable for storage if they could be recontainerized. If not naturally occurring, potassium hydroxide would occur underground only as a treatment product of potassium dinitrobenzfuroxan (KDNBF) (as munitions) and cadmium potassium cyanide.

Table 12 (continued). HAZARDOUS REACTIONS

Reaction	Explanation
Reaction GG Potassium Hydroxide with 2, 4-D	
Reaction KK Potassium Hydroxide with Demeton	
Reaction NN Potassium Hydroxide with Chromium Hydroxide	
Reaction SS Potassium Hydroxide with Lead Arsenate	
Reaction F Sodium Hydroxide with Calcium Arsenate	The only hazards associated with the sodium hydroxide reactions is that the resulting compounds of sodium are toxic, and are more soluble in water than the original compounds. This solubility does increase their potential for migration out of the mine, but does not render them unacceptable as long as they can be properly containerized. Sodium hydroxide may occur underground as a product of the treatment of arsenic trichloride or lewisite. Since both of these substances require mixing with a base at some point in their treatment, either sodium hydroxide or calcium hydroxide may be used. Calcium hydroxide is preferred since the calcium compounds formed are less soluble than the sodium compounds, although both are storable underground. It is probable, therefore, that sodium hydroxide would not be found as a treatment product underground, however, its possible use is not precluded.
Reaction G Sodium Hydroxide with Calcium Arsenite	
Reaction H Sodium Hydroxide with Magnesium Arsenite	
Reaction L Sodium Hydroxide with Zinc Arsenite	
Reaction O Sodium Hydroxide with Arsenic Trioxide	
Reaction W Sodium Hydroxide with Lead Oxide	
Reaction Y Sodium Hydroxide with Lead Arsenate	
Reaction Z Sodium Hydroxide with Zinc Arsenate	
Reaction EE Sodium Hydroxide with Guthion	
Reaction II Sodium Hydroxide with 2, 4-D	

Table 12 (continued). HAZARDOUS REACTIONS

Reaction	Explanation
Reaction MM Sodium Hydroxide with Demeton Reaction OO Sodium Hydroxide with Chromium Hydroxide Reaction RR Sodium Hydroxide with Lead Arsenite	
Reaction J Zinc Arsenite with Calcium Hydroxide Reaction M Zinc Arsenite with Calcium Silicate	The only hazard associated with these reactions is that the calcium arsenite formed is more soluble than the zinc arsenite. Although calcium arsenite is more soluble and has a greater potential for migration out of the mine, it is still an acceptable form for underground storage if properly containerized. Calcium hydroxide may occur underground as a product of the treatment of antimony pentafluoride, antimony trifluoride, arsenic trichloride, fluorine, GB, or lewisite. Calcium silicate occurs only as a treatment product of fluorine if the fluorine is contaminated with silicon tetrafluoride prior to treatment.
Reaction PP Benzene Hexachloride with Potassium Hydroxide Reaction QQ Benzene Hexachloride with Sodium Hydroxide	Benzene hexachloride is dehydrochlorinated to trichlorobenzene in the presence of alkali. The trichlorobenzene is probably less toxic but it would create a slightly greater flammability hazard than the benzene hexachloride. Trichlorobene would be classed as optionally acceptable for underground storage in proper containers due to its slight flammability and potential for liberation of toxic, flammable, and possibly explosive gases when heated to decomposition.

Table 12 (continued). HAZARDOUS REACTIONS

Reaction	Explanation
Reaction P Lead Oxide with Potassium Arsenite Reaction T Lead Oxide with Sodium Arsenate Reaction U Lead Oxide with Sodium Arsenite Reaction V Lead Oxide with Sodium Cacodylate	Lead oxide in the presence of water and potassium arsenite or sodium arsenate, arsenite or cacodylate may form potassium or sodium plumbate and arsenous arsenic or cacodylic acid. The plumbates which are formed are more soluble in water than the original lead oxide, however, they would be acceptable for underground storage if they could be properly containerized. The acids formed are also water soluble and may have a detrimental effect on some geological formations
Reaction BB Potassium Arsenite with Guthion Reaction FF Potassium Arsenite with 2, 4-D Reaction JJ Potassium Arsenite with Demeton Reaction DD Sodium Arsenite with Guthion Reaction HH Sodium Arsenite with 2, 4-D Reaction LL Sodium Arsenite with Demeton	These arsenites hydrolize in water to form a strong base and weak arsenous acid. The strong base may react with 2, 4-D to form the more soluble potassium or sodium salt of 2, 4-D. The strong base catalyzes the hydrolysis of guthion or demeton to form a more soluble hydrolysis product. This soluble product may be nearly as toxic as the original compound.
Reaction X Sodium Chloride with Lead Oxide	The result of this reaction may be a sodium chloride-lead oxide complex. This complex is soluble and constitutes a greater hazard than the original PbO.

Table 12 (continued). HAZARDOUS REACTIONS

Reaction	Explanation

RECOMMENDATION

Discretion should be used when the substances included as the initial reactants in reactions A through SS are being stored underground. There is a possibility of more hazardous compound being formed if a reactant is stored in proximity to some other reactant. It is therefore recommended that the substances mentioned above not be stored in proximity to each other underground.

As a result of this investigation, it was found that most of the hazardous reactions increased the solubility of the wastes. The ramifications of this type of reaction are twofold. In the short-term, an increase in solubility would result in an increase in chemical reactivity thereby increasing a waste's potential to take part in further reactions. In the long-term, an increase in solubility would increase the potential of a waste to migrate from the mine environment by keeping the waste in solution for a longer time. It should be stressed that the interaction of the wastes can be controlled through proper treatment and containerization thereby maximizing the protection of the environment.

STEP 9 - GEOCHEMICAL INTERACTION AND COMPATIBILITY

The purpose of the geochemical study was to determine the compatibility of the geological and chemical investigations in a field condition. Since environmentally unfavorable reactions may occur from the chemical interaction of the stored wastes with the receiving geological formations, this evaluation was a necessary step in determining the environmental acceptability of the concept. An unfavorable reaction would be one in which any of the following might occur:

1. The potential for migration of a waste is heightened by an increase in its solubility through complexing or ionization.
2. The structural integrity of the lithology is unfavorably altered.
3. Any new substances are formed which present greater hazards to the environment than the original substances.

In a favorable reaction, the reverse of the above would be true. If an unfavorable reaction occurs, a waste is said to be incompatible in a lithology. If a favorable reaction or no reaction occurs, a waste is said to be compatible in a lithology.

The lithologies which have been selected as candidate formations for storage are:

1. Rock salt (Halite)
2. Gypsum
3. Potash (Sylvite)
4. Shale(1) (Relatively high montmorillonite content)
5. Shale(2) (Relatively low montmorillonite content)
6. Limestone
7. Granite

For the purposes of this analysis, it was assumed these lithologies were homogeneous in composition and that any impurities which would normally be found with them would not occur in amounts sufficient to alter the basic reactions between the wastes and the lithology.

In this investigation, the "worst case" analysis was again employed. In this analysis, the storable wastes were assumed to be in contact with the selected lithologies under both wet and dry conditions. These conditions would not be possible unless the waste containers were ruptured by some calamity such as flooding. The resulting reactions were classed as favorable or unfavorable. Although the conditions allowing the interaction of the wastes and receiving formations could be controlled through proper treatment and containerization, this analysis was performed to ensure the appraisal of all conditions which might adversely affect the environment.

The discussion of the types of reactions which may occur should be qualified by stating that all the reactions, with the exception of chloride complexing, are relatively slow. Years may be required before any detrimental effects on the environment are realized. However, since both long and short-term effects are within the scope of this study, these reactions were assessed.

It should be noted that the reactions presented here are only the immediate or first level reactions. As with the interaction of the wastes, the enormous number of possible chain reactions precludes their investigation within the scope of this study. However, further research in this area is recommended.

Rock Salt (Halite) And Potash (Sylvite)

Rock salt and potash are grouped together because of similarities in chemical behavior. The principal constituents of rock salt and potash are readily soluble in water to form a solution of near neutral pH. If toxic ions are present in this solution, highly soluble chloride complexes will form. The rate at which these complexes are formed depends upon the availability of the toxic ions which, in turn, depends upon the amount of the original toxic compound and the pH of the solution. For example, if Lead Oxide (PbO) were to come into contact with a solution containing dissolved rock salt or potash at neutral pH, the rate of complexing would be slow because PbO is not readily ionized at neutral pH. However, if the pH of the solution was varied from neutral by the presence of another waste, the rate of complexing would increase with the degree of variance due to the larger availability of lead or plumbite ions created by the change in pH. Since chloride complexing creates toxic compounds which are more soluble than the original toxic compounds and thereby are potentially more hazardous, wastes which would take part in such reactions are classed as being incompatible in rock salt or potash.

Gypsum

Although reactions between some of the storable wastes and gypsum did occur, none were found to be of an unfavorable nature. For this reason, all of the wastes found acceptable for storage are compatible with this lithology.

Shale

Principally, there are two types of unfavorable reactions which may occur in shales (1) and (2). In the presence of a solution which contains sodium ion, the montmorillonite in shales (1) and (2) exhibits thixotropic properties (deflocculates into a jelly-like material) reducing the structural capabilities of the entire shale. Due to this unfavorable alteration, wastes having the potential for releasing sodium ions in solution are classed as incompatible in shale (1) or (2). In the presence of a solution of low pH (acidic), the montmorillonite in shales (1) and (2) undergoes a change in composition. Although the results of this change are not necessarily unfavorable, potentially unfavorable alterations in the structural stability of the shale during the change may take place. For this reason, wastes with the potential of forming acidic solutions, or which are in themselves acidic solutions, are classed as incompatible in shale (1) or (2).

The rate of these reactions depends upon the amount of available surface area of shale, the permeability of the shale, the concentration of ions in the waste solution, and the ion exchange capacity of the shale. An increase in these factors will bring about an increase in the rate of reaction. Since some of these factors may be increased by an increase in the montmorillonite content of a shale, shale (2) may generally be said to be a more favorable lithology for the storage of hazardous wastes.

Limestone

Unfavorable reactions occur in limestone in the presence of solutions of low pH (acidic). The limestone is dissolved by the acid solution with the liberation of CO_2. With an increase in the strength of the acid, the rate of this reaction increases with a correspondingly greater amount of CO_2 evolvement. Since dissolving the limestone decreases its structural capabilities, a reaction of this type would be unfavorable. For this reason, wastes with the potential of forming fairly strong acidic solutions, or which are in themselves fairly strong acidic solutions, would be classed as incompatible in limestone.

Granite

In the presence of solutions which are acidic, the potash feldspar minerals in granite undergo hydrolysis and are changed into different minerals. In the presence of solutions which are basic (above pH 9), the solubility of the silica minerals in granite increases abruptly due to ionization. These reactions would be unfavorable because the structural capabilities of the granite would be reduced. For this reason, wastes which would form strongly acidic or basic solutions or which are in themselves strongly acid or basic solutions, would be classed as incompatible in granite. It should be noted, however, that the rate of the hydrolysis reaction in granite is very slow. This rate of reaction depends upon the pH of the solution and the degree of fracturing in the granite. The greater the extent of either of these factors, the greater the rate of reaction.

To illustrate the types of reactions which may occur and the compatibility of the stored wastes and lithologies, two matrices have been developed and are presented in Table 13 and Table 14.

STEP 10 - WASTE MIGRATION

The primary result of the investigation of the potential environmental effects of waste migration is that migration can be avoided if the proper techniques of waste treatment and containerization are employed. Since the goal of underground storage is the complete isolation of the hazardous wastes from the biosphere, the potential migration of the wastes must be controlled. From a chemical point of view, there are two principle methods by which a waste may migrate.

1. Carried by ground water.
2. Reacting with host rock.

Both of these methods are primarily controlled by the solubility of a waste. Therefore, decreasing the solubility of a waste during treatment should be of major concern. Perhaps the best method of avoiding migration is through the use of containers. If a stored waste is never allowed to contact the mine environment, there would be no chance of it escaping. The disadvantage of containers is that their use could become economically prohibitive. It is recommended that research in the area of the containerization or encapsulation of the wastes be done to determine the controlling economic factors.

It should be noted that, if a waste should escape the container, the rate of migration by ground water or reaction with the lithology is extremely slow, ranging from several hundred to thousands of years. The tendency of ground water, in most cases, is to move into a mine rather than out and, as mentioned in Step 9, waste/lithology reactions do not proceed quickly. However, the eventual effects of the migration of a waste once it leaves the mine environment are not known. The rate of movement, the distance a waste will travel, and the potential chemical changes in the waste or environment which may take place vary from site to site and will require further research. Research in this area is a recommendation of this study.

KEY TO TABLE 13

O: Negligible to no reaction.

1*: Possible to weak reaction.

2**: Weak to moderate reaction.

IE: Ion exchange.

  a. IE_1: Weak to moderate ion exchange.

  b. IE_2: Strong ion exchange.

Cor: Possible clay-mineral-organic reactions: it includes ion exchange and absorption.

* Equivalent to silicate hydrolysis (i.e., granite hydrolysis)

* and ** equivalent to stability reactions in case of shales.

† Shale: 1. Relatively high montmorillonite content.

2. Relatively low montmorillonite content.

Table 13. GEOCHEMICAL REACTIVITY MATRIX

Hazardous waste		Rock type						
Name	(Untreated wastes) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
13 **Aldrin**	$C_{12}H_8Cl_6$	0	0	0	0	0	0	0
51 **Arsenic Trioxide**	As_2O_3	0	0	0	$1, IE_2$	$1, IE_1$	1	1
55 **Benzene Hexachloride**	$C_6H_6Cl_6$	0	0	0	Cor	Cor	0	0
80 **Cacodylic Acid**	$(CH_3)_2AsO_2H$	0	0	0	1	1	2	1
81 **Cadmium (as a solid)**	Cd	0	0	0	0	0	0	0
83 **Cadmium Chloride**	$CdCl_2$	1	0	1	$1, IE_2$	$1, IE_1$	1	0
478 **Cadmium Fluoride**	CdF_2	0	1	0	$1, IE_2$	$1, IE_1$	1	1
85 **Cadmium Oxide**	CdO	0	0	0	0	0	0	0
86 **Cadmium Phosphate**	$Cd(PO_4)_2$	0	0	0	0	0	0	0
481 **Cadmium Sulfate**	$CdSO_4$	0	0	0	$1, IE_2$	$1, IE_1$	1	0
87 **Calcium Arsenate**	$Ca_3(AsO_4)_2$	0	0	0	$1, IE_2$	$1, IE_1$	1	1

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Untreated wastes) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
88 Calcium Arsenite	$CaHAsO_3$	0	0	0	IE_2	IE_1	0	1
490 Copper Acetoarsenite	$(C_2H_3O_2)_2$ Cu · $3Cu(AsO_2)_2$	0	0	0	0	0	1	0
119 Copper Arsenate	$Cu_3(A_3O_4)_2$	0	0	0	IE_1	0	0	0
136 DDD	$(ClC_6H_4)_2\ C_2H_2Cl_2$	0	0	0	0	0	0	0
137 DDT	$(ClC_6H_4)_2\ C_2HCl_3$	0	0	0	0	0	0	0
491 Demeton	$C_8H_{19}O_3S_2P$	0	0	0	Cor	Cor	0	0
135 2, 4-D	$C_8H_6Cl_2O_3$	0	0	0	2	2	1	1
149 Dieldrin	$C_{12}H_8OCl_6$	0	0	0	0	0	0	0
170 Endrin	$C_{12}H_8Cl_6O$	0	0	0	0	0	0	0
495 Guthion	$C_{10}H_{12}N_3O_3S_2P$	0	0	0	Cor	Cor	0	0
496 Heptachlor	$C_{10}H_5Cl_7$	0	0	0	0	0	0	0

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Untreated wastes) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
235 Lead Arsenate	$PbHAsO_4$	0	0	0	IE_1	0	0	0
236 Lead Arsenite	$Pb(AsO_2)_2$	0	0	0	IE_1	0	0	0
245 Magnesium Arsenite	$Mg_3(AsO_3)_2$	0	0	0	$1,IE_2$	$1,IE_1$	1	0
500 Manganese Arsenate	$MnHAsO_4$	0	0	0	IE_1	0	0	0
322 Pentachlorophenol	C_6HOCl_5	0	0	0	0	0	0	0
341 Potassium Arsenite	$KAsO_2$	0	1	0	$2,IE_2$	$2,IE_1$	0	1
376 Sodium Arsenate	Na_2HAsO_4	0	1	0	$2,IE_2$	$2,IE_1$	0	1
377 Sodium Arsenite	Na_3AsO_3	0	1	0	$2,IE_2$	$2,IE_1$	0	1
382 Sodium Cacodylate	$C_2H_6O_2AsNa$	0	1	0	$2,IE_2$	$2,IE_1$	0	1
453 Zinc Arsenate	$Zn_3(AsO_4)_2$	0	0	0	0	0	0	0
454 Zinc Arsenite	$Zn(AsO_2)_2$	0	0	0	$1,IE_2$	$1,IE_1$	0	0

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Treatment products) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
21 Ammonium Chromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
22 Ammonium Dichromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
27 Ammonium Picrate (dry as munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
28 Ammonium Picrate (wet as munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
36 Antimony Pentafluoride	$CaF_2+CaCl_2+Ca(OH)_2+H_2O$, Sb	0	0	0	2, IE_2	2, IE_1	0	1
43 Antimony Trifluoride	$CaF_2+CaCl_2+Ca(OH)_2+H_2O$, Sb	0	0	0	2, IE_2	2, IE_1	0	1
50 Arsenic Trichloride	$Ca_3(AsO_3)_2+CaCl_2+Ca(OH)_2+H_2O$	0	0	0	2, IE_2	2, IE_1	0	1
82 Cadmium, Powdered	Cd	0	0	0	0	0	0	0
84 Cadmium Cyanide	$CdO + H_2O$	0	0	0	0	0	0	0
479 Cadmium Nitrate	$CdO + H_2O$	0	0	0	0	0	0	0
480 Cadmium Potassium Cyanide	$CdO + H_2O$	0	0	0	0	0	0	0

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Treatment products) Formula	Rock salt	Gypsum	Potash	Shale: $1^{\dagger}$	Shale: $2^{\dagger}$	Limestone	Granite
114 Chromic Acid	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
517 Copper Acetylide	$CuO + CuCO_3$	0	0	0	0	0	0	0
518 Copper Chlorotetrazole	CuO	0	0	0	0	0	0	0
120 Copper Cyanide	$Cu(OH)_2+CuCO_3+H_2O$	0	0	0	0	0	0	0
128 Cuprous (Copper) Cyanide	$Cu(OH)_2 + CuCO_3 + H_2O$	0	0	0	0	0	0	0
129 Cyanides	Metal hydroxides or carbonates + H_2O	0	0	0	0	0	0	0
520 Detonators & Primers	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
521 Diazodinitrophenol (DDNP) (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
165 Dinitrotoluene (DNT) (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
522 Dipentaerythritol Hexanitrate (DPEHN)(munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
200 Fluorine	$CaF_2+CaSiO_3+Ca(OH)_2+H_2O$	0	0	0	2,IE_2	2,IE_1	0	1

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste			Rock type						
	Name	(Treatment products) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
287	GB	$CaF_2+Ca_2P_2O_7+CaCO_3+Ca(OH)_2+H_2O$	0	0	0	2,IE_2	2,IE_1	0	1
523	Gelatinized Nitrocellulose (PNC) (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
529	Lead Azide(nonmunitions)	Pb	0	0	0	0	0	0	0
529	Lead Azide (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
239	Lead Cyanide	$PbO + H_2O$	1	0	1	IE_2	IE_1	0	0
530	Lead 2,4 Dinitrorecorcinate (LDNR)(nonmunitions)	PbO	1	0	1	IE_2	IE_1	0	0
530	Lead 2,4 Dinitrorecorcinate (LDNR)(munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
531	Lead Styphnate (nonmunitions)	PbO	1	0	1	IE_2	IE_1	0	0
531	Lead Styphnate (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
243	Lewisite	$CaCl_2+Ca_3(AsO_3)_2+Ca(OH)_2+H_2O$	0	0	0	2,IE_2	2,IE_1	0	1
532	Mannitol Hexanitrate (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Treatment products) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
533 Mercuric Fulminate (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
295 Nickel Cyanide	$NiO + H_2O$	0	0	0	0	0	0	0
307 Nitroglycerine (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
319 Pentaerythritol Tetranitrate (PETN) (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
338 Picric Acid (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
343 Potassium Chromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
345 Potassium Dichromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
536 Potassium Dinitrobenzfuroxan(KDNBF)(munitions)	Metal oxides + PbO + KOH	2	0	2	2,IE_2	2,IE_1	0	1
370 Silver Cyanide	$AgCl + H_2O$	1	0	1	IE_2	IE_1	0	0
541 Smokeless Gunpowder (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
386 Sodium Chromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0

Note: Reactions indicated occur under wet conditions.

Table 13 (continued).

Hazardous waste		Rock type						
Name	(Treatment products) Formula	Rock salt	Gypsum	Potash	Shale: 1†	Shale: 2†	Limestone	Granite
379 Sodium Dichromate	$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
418 TNT (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
542 Tetrazene (munitions)	Metal oxides + PbO	1	0	1	IE_2	IE_1	0	0
Note: The following are included due to their possible occurrence as treatment products:								
Magnesium Hydroxide	$Mg(OH)_2$	0	0	0	0	0	0	1
Magnesium Arsenate	$Mg_3(AsO_4)_2$	0	0	0	0	0	0	0
Sodium Chloride	$NaCl$	0	0	0	IE_2	IE_1	0	0
Sodium Hydroxide	$NaOH$	0	0	0	IE_2	IE_1	0	1

Note: Reactions indicated occur under wet conditions.

Table 14. GEOCHEMICAL COMPATIBILITY MATRIX

Untreated wastes	Rock salt	Gypsum	Potash	Shale(1)	Shale(2)	Limestone	Granite
Aldrin	0	0	0	0	0	0	0
Arsenic Trioxide	0	0	0	1	1	1	1
Benzene Hexachloride	0	0	0	0	0	0	0
Cacodylic Acid	0	0	0	1	1	1	1
Cadmium	0	0	0	0	0	0	0
Cadmium Chloride	0	0	0	0	0	1	0
Cadmium Fluoride	0	0	0	1	1	1	1
Cadmium Oxide	0	0	0	0	0	0	0
Cadmium Phosphate	0	0	0	0	0	0	0
Cadmium Sulfate	0	0	0	1	1	1	0
Calcium Arsenate	0	0	0	0	0	0	0
Calcium Arsenite	0	0	0	0	0	0	0
Copper Acetoarsenite	0	0	0	0	0	0	0
Copper Arsenate	0	0	0	0	0	1	0
DDD	0	0	0	0	0	0	0
DDT	0	0	0	0	0	0	0
Demeton	0	0	0	0	0	0	0
2, 4-D	0	0	0	1	1	1	1
Dieldrin	0	0	0	0	0	0	0
Endrin	0	0	0	0	0	0	0
Guthion	0	0	0	0	0	0	0
Heptachlor	0	0	0	0	0	0	0
Lead Arsenate	0	0	0	0	0	0	0
Lead Arsenite	0	0	0	0	0	0	0
Magnesium Arsenite	0	0	0	0	0	1	0
Manganese Arsenate	0	0	0	0	0	0	0
Pentachlorophenol	0	0	0	0	0	0	0
Potassium Arsenite	0	0	0	0	0	0	0
Sodium Arsenate	0	0	0	1	1	0	1
Sodium Arsenite	0	0	0	1	1	0	1
Sodium Cacodylate	0	0	0	1	1	0	1

Table 14 (continued). GEOCHEMICAL COMPATIBILITY MATRIX

Untreated wastes	Rock salt	Gypsum	Potash	Shale(1)	Shale(2)	Limestone	Granite
Zinc Arsenate	0	0	0	0	0	0	0
Zinc Arsenite	0	0	0	0	0	0	0
Treatment Products	**Rock salt**	**Gypsum**	**Potash**	**Shale(1)**	**Shale(2)**	**Limestone**	**Granite**
$Cr(OH)_3 + H_2O$	0	0	0	0	0	0	0
Metal Oxides + PbO	1	0	1	0	0	0	0
$CaF_2+CaCl_2+H_2O+Ca(OH)_2$	0	0	0	0	0	0	0
Sb	0	0	0	0	0	0	0
$Ca_3(AsO_3)_2+CaCl_2+Ca(OH)_2+H_2O$	0	0	0	0	0	0	0
Cd	0	0	0	0	0	0	0
$CdO+H_2O$	0	0	0	0	0	0	0
$CuO+CuCo_3$	0	0	0	0	0	0	0
$Cu(OH)_2+CuCO_3+H_2O$	0	0	0	0	0	0	0
Metal Hydroxides+H_2O	0	0	0	0	0	0	0
Metal Carbonates	0	0	0	0	0	0	0
$CaF_2+CaSiO_3+Ca(OH)_2+H_2O$	0	0	0	0	0	0	0
$CaF_2+Ca_2P_2O_7+CaCO_3+Ca(OH)_2+H_2O$	0	0	0	0	0	0	0
Pb	0	0	0	0	0	0	0
$PbO+H_2O$	1	0	1	0	0	0	0
PbO	1	0	1	0	0	0	0

Table 14 (continued). GEOCHEMICAL COMPATIBILITY MATRIX

Treatment Products	Rock salt	Gypsum	Potash	Shale(1)	Shale(2)	Limestone	Granite
$CaCl_2+Ca_3(AsO_3)_2+$ $Ca(OH)_2+H_2O$	0	0	0	0	0	0	0
$NiO+H_2O$	0	0	0	0	0	0	0
Metal Oxides+KOH+ PbO	1	0	1	0	0	0	1
$AgCl+H_2O$	1	0	1	0	0	0	0
Note: The following are included due to their possible occurrence as treatment products:							
$Mg(OH)_2$	0	0	0	0	0	0	1
$Mg_3(AsO4)_2$	0	0	0	0	0	0	0
Nacl	0	0	0	1	1	0	0
NaOH	0	0	0	1	1	0	1

Legend
0 = compatible for storage (favorable reaction may occur)
1 = incompatible for storage (unfavorable reaction occurs)

STEP 11 - PROJECTED WASTE VOLUMES

The last step in evaluating the wastes as candidates for underground storage is to investigate their probable volumes. This is important in order to obtain some idea of the magnitude of the problem of waste disposal and to assess mined storage as a potential answer. In accordance with the contract directive, current waste volumes were obtained from available sources and projected to estimate the volumes of waste in the years 1975, 1980, and 1985. This work is presented in Appendix B-4. The information contained in Appendix B-4 is subdivided by industries identified by their Standard Industrial Classification Code (SIC Code). Under each industry heading are listed the wastes which are either produced or used by that industry and would probably appear in its waste streams. Immediately following is the geographical percentage distribution of the wastes from that industry as obtained from available sources.

The order in which the wastes are listed under each industry heading is significant. The initial group of wastes contains those which are acceptable for underground storage in containers with no pretreatment. The second grouping of wastes contains those which are acceptable for underground storage in containers after treatment. The third grouping contains all other wastes. A lack of reliable information was encountered in this task. Much of the available data was incomplete, and inconclusive. Although conclusions were attempted from this data, it must be noted that these conclusions, may be inaccurate. Extensive research in this area is sorely needed. It is a recommendation of this study that this research be accomplished.

Although distribution data was available in some cases, it was not possible to quantify the volumes of candidate wastes from the following industries.

1. SIC 10 - Metal mining.
2. SIC 24 - Lumber and wood.
3. SIC 2834 - Pharmaceutical preparations.
4. SIC 32 - Stone, clay, glass, and concrete products.
5. SIC 33 - Primary metals industries.
6. SIC 3573 - Computers.
7. SIC 36 - Battery manufacture, electronics, mechanical, magnetic tape production.
8. SIC 49 - Electric, gas, and sanitary services.

One result of the volume study was that some of the wastes did not occur in significant amounts. In such cases, it may be more feasible to treat these wastes at the point of origin. Table 15 lists the wastes of concern which occur in negligible amounts. Although these wastes did not occur in significant volumes, they were screened for acceptability on the same basis as other wastes to account for the possibility of a future increase in generation.

Table 15. CANDIDATE WASTES WHICH OCCUR IN SUCH SMALL VOLUMES THAT ON-SITE TREATMENT AT THE ORIGIN OF THE WASTE IS RECOMMENDED.

ID. No.	Substance	ID. No.	Substance
8	Acrolein	236	Lead Arsenite
61,505	Boron Hydrides	500	Manganese Arsenate
480	Cadmium Potassium Cyanide	293	Nickel Carbonyl
		505	Pentaborane
88	Calcium Arsenite	341	Potassium Arsenite
119	Copper Arsenate	537	Silver Acetylide
518	Copper Chlorotetrazole	538	Silver Azide
120	Copper Cyanide	539	Silver Styphnate
136	DDD	540	Silver Tetrazene
526	Gold Fulminate		

To summarize the results of waste characterization, Figure 21 was developed. These results indicate that 99.99 percent of the total treated and untreated candidate waste volume is acceptable for underground storage. The volume of unacceptable wastes occurs almost entirely from the use of Mercury and its compounds. Since the use of Mercury is presently declining, the percentage of problem solution offered by the underground storage of hazardous wastes is believed to be valid.

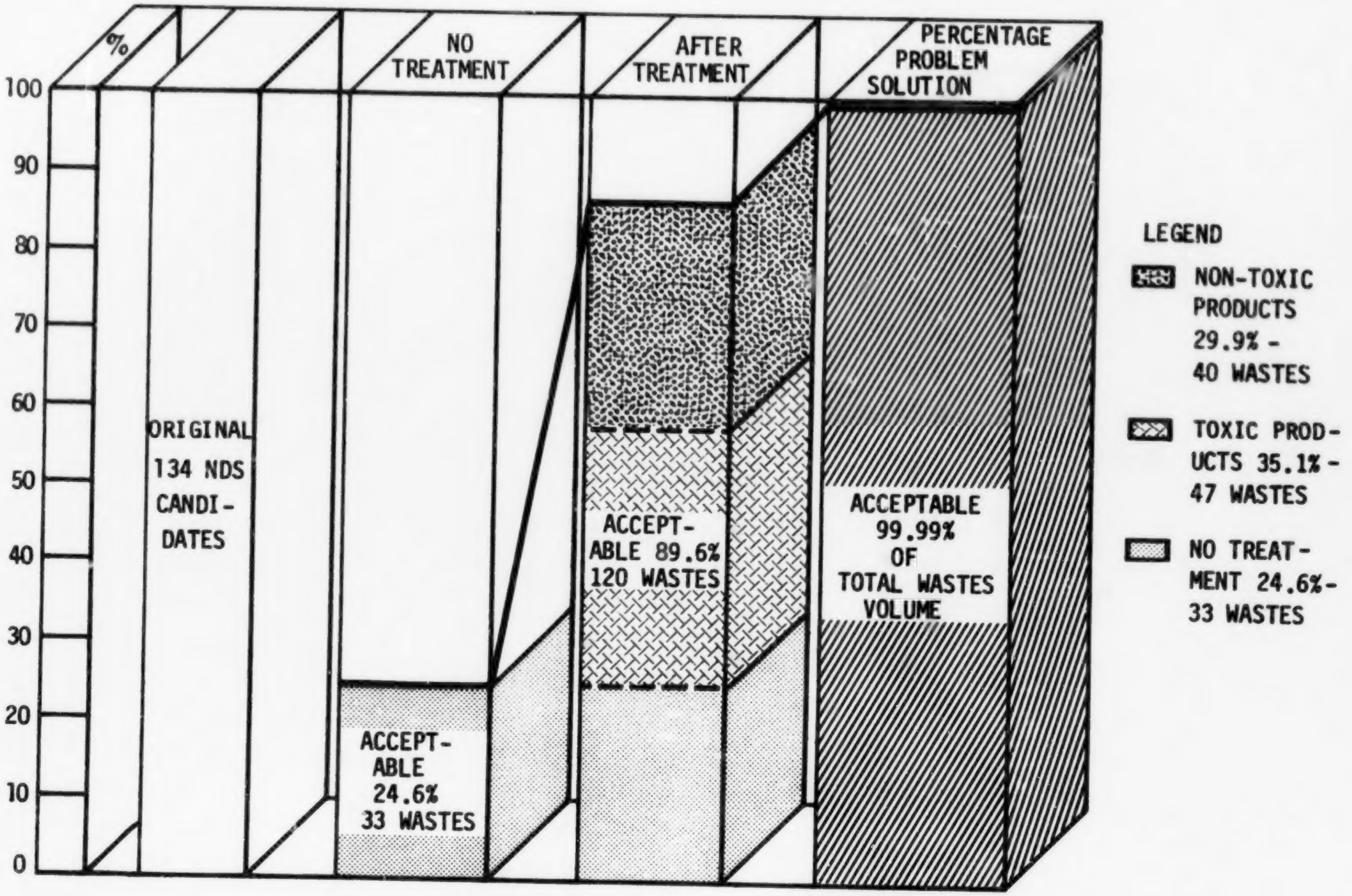


Figure 21. Percentage Problem Solution.

SECTION 7

DETECTION, MONITORING AND CONTROL

The emplacement, storage, and management of noxious chemical wastes in underground mined openings will require continuous surveillance of the mine opening, contiguous subsurface areas, and surface environments. The purpose of mined storage is to safely isolate hazardous wastes from the biosphere. The implementation of detection monitoring and control systems will help insure isolation and safety by providing early warning of contamination in air and water and will also allow early detection of structural fatigue. By these means the potential for waste interaction with the biosphere can be strictly controlled.

MINE ATMOSPHERE

The basic requirements of a detection, monitoring, and control system will include the following:

1. Continuously monitor, sample, and clean the circulating mine air.
2. Provide immediate response (alarms, etc.) to critical changes.
3. Indicate long-term finite changes.
4. Allow source area identification.
5. Provide qualitative and quantitative analysis of contaminants in air and water.
6. Provide high reliability.
7. Be adaptable to change and improvement as the technology advances.
8. Provide decontamination capability.
9. Allow recovery and storage of released wastes.

The criterion that wastes be containerized prior to emplacement is due partly to the problem of safe transport and storage in a closed environment. Many of the wastes have very low TLV's; thus, even minor releases are potentially very serious.

The contaminants may occur as particulates or gases and can be monitored and controlled using several available techniques. Appendix C lists some of the instruments and techniques which are commonly used or presently being developed. Many of these methods may be integrated to provide a wide range of coverage and control.

In researching the subject, it was apparent that the state-of-the-art is rapidly evolving with new and improved instruments and techniques. It is expected that much of the future technology will be adaptable to the special needs of mined waste storage.

PHYSICAL MINE STRUCTURE

The importance of monitoring the short and long-term structural integrity of a mine used for housing hazardous wastes involves several aspects of this storage concept. Of immediate interest is the safety of personnel working in the facility. Such things as roof falls, slabbing, etc. are hazards which can normally be prevented by good maintenance practices. Hazards of a larger consequence would result if such failures were to rupture containers. If this occurred, not only would mine personnel be put in jeopardy, but the entire waste facility might be lost temporarily, or even permanently. To guard against such an occurrence, mines must be selected with high regard to stability; and to provide additional insurance, various monitoring instruments and techniques should be implemented. Instruments which are presently available can provide finite measurements of short and long-term changes and thus allow preventative measures to be taken before failure occurs.

The first step undertaken should be to conduct high-level surveys of the mined space. Such surveys can then be used as standards for comparing future surveys to assess possible alterations. Modern laser technology might prove valuable in this type of program; however, specific instrumentation and techniques may have to be designed to fit the problem.

Most commonly available instruments are designed to measure finite changes in stress (load), strain (deformation), convergence, and microseismic movement. Extensometers are proven detectors of low magnitude deformation of supporting structures. They can be permanently (or temporarily) installed in any critical area, including roof, walls, pillars, and floor. Measurements can be made periodically on location, or they can be designed for remote telemetry and monitored at any time. Installation is relatively simple, and the cost is low to moderate depending on the system required.

Other monitoring instruments are capable of measuring finite convergence between roof and floor, walls, pillars, etc. There are many such detectors available to provide several levels of control and most are, or can be, remotely monitored.

Geophones are used to detect the minute movements indicative of released stress and strain. By noting changes in microseismic frequency and magnitude, potential problems can be detected early. All of these devices can be adapted to remote monitoring telemetry.

A complete structural monitoring system will be vital to a mined storage facility from the standpoints of safety, containment and retrievability.

AREA HYDROLOGY

The hydrologic environment in the area of a hazardous waste storage facility will require monitoring to assure isolation of the wastes and protection to the environment. Streams, springs, and wells in the vicinity can be physically sampled using standard methods and the samples then analyzed in a laboratory.

All significant aquifers in proximity to the mine should be identified and their physical features established. Such studies should determine if subsurface water is migrating and, if so, in what direction and at what rate. In addition, natural static pressure, upper and lower limits, and natural particulate load (salinity) should be determined. The salinity analysis should be thorough since it will be useful as a standard for future analysis. Once these hydrologic parameters are determined, perimeter monitoring wells can be sited. The best configuration will depend on the previous investigations, but at least two perimeters should be included for adequate control. The total number of wells needed will vary from site to site.

Most systems used to monitor migrating subsurface water include perimeter monitoring wells for physical sampling. Since these wells are typically small diameter, in-hole instrumentation is limited to small probes. Available instruments which can be used continuously or periodically and monitored remotely or in the field were developed to measure water level changes, conductivity, PH, and temperature. Probes to measure other physical parameters also exist, or can be developed as the need is recognized.

High-level monitoring techniques require water sampling for laboratory analysis. Many of the instruments described in Appendix C can be used for this purpose.

Mine water, if it occurs naturally might be controlled using sumps. A mine opening will alter the natural hydrostatic environment when aquifer communication exists. Since the mine space is at atmospheric pressure, aquifers surrounding the opening will tend to drain toward the mine as long as it is open. Should contamination of mine water occur, migration away from the mine opening will be naturally retarded.

SUMMARY

The review of detection, monitoring, and control technology indicates that the state-of-the-art is adequate to meet the requirements and conditions of mined waste storage Available and developing instrumentation can be combined to provide extremely sensitive, wide spectrum analysis of the subsurface environment. Table 16 lists the types of instrumentation available for analyzing and monitoring the storable wastes.

Table 16. ANALYTICAL AND MONITORING TECHNIQUES FOR STORABLE WASTES

Legend:

● - Primary Method
○ - Secondary Method

Stored Wastes	Visible spectrometry	Ultraviolet spectrometry	Infrared spectrometry	Atomic absorption spectrometry	Flame emission spectrometry	Emmission spectrometry	Turbidimetry	Potentiometry	Mass spectrometry	Gas chromatography
Aldrin	○	○	●						●	●
Antimony	●	●								
Arsenic trioxide	●	●						●		
Benzene hexachloride	○	○	●						●	●
Cacodylic acid	●	●	●					●		
Cadmium	●	●		●		●				
Cadmium chloride	●	●		●		●		●		
Cadmium fluoride	●	●		●		●				
Cadmium oxide	●	●		●		●				
Cadmium phosphate	●	●		●		●				
Cadmium sulfate	●	●		●		●				
Calcium arsenate	○	○		●	●	●	●			
Calcium arsenite	○	○		●	●	●	●			
Calcium carbonate				●	●	●	●	○		
Calcium chloride				●	●	●	●	●		
Calcium fluoride				●	●	●	●	●		
Calcium hydroxide				●	●	●	●	●		
Calcium pyrophosphate	●	●		●	●	●	●	●		
Calcium silicate	●	●		●	●	●	●	●		
Chromic hydroxide	●	●		●		●				
Copper acetoarsenite	●	●		●		●				
Copper arsenate	●	●		●		●				
Copper carbonate	●	●		●		●				
Copper hydroxide	●	●		●		●				
Copper oxide	●	●		●		●				
DDD	○	○	●						●	●
DDT	○	○	●						●	●
Demeton	○	○	●			●			●	●

Table 16 (continued). ANALYTICAL AND MONITORING TECHNIQUES FOR STORABLE WASTES

Stored Wastes	Visible spectrometry	Ultraviolet spectrometry	Infrared spectrometry	Atomic absorption spectrometry	Flame emission spectrometry	Emission spectrometry	Turbidimetry	Potentiometry	Mass spectrometry	Gas chromatography
2,4-D	○	○	●						●	●
Dieldrin	○	○	●						●	●
Endrin	○	○	●						●	●
Guthion	○	○	●			●			●	●
Heptachlor	○	○	●						●	●
Lead	●	●		●		●				
Lead arsenate	●	●		●		●				
Lead arsenite	●	●		●		●				
Lead oxide	●	●		●		●				
Magnesium arsenate	○	○		●	●	●	●			
Magnesium arsenite	○	○		●	●	●	●			
Magnesium hydroxide				●	●	●	●			
Manganese arsenate	●	●		●		●				
Metal carbonates	●	●		●		●				
Metal hydroxides	●	●		●		●				
Metal oxides	●	●		●		●				
Nickel oxide	●	●		●		●				
Pentachlorophenol	○	○	●						●	●
Potassium arsenite	○	○		●	●	●		●		
Potassium hydroxide				●	●	●		●		
Silver chloride	●	●		●		●	●			
Sodium arsenate	○	○		●	●	●		●		
Sodium arsenite	○	○		●	●	●		●		
Sodium cacodylate	○	○	●	●	●	●		●		
Sodium chloride				●	●	●	●	●		
Sodium hydroxide				●	●	●		●		
Zinc arsenate	●	●		●		●				
Zinc arsenite	●	●		●		●				

SECTION 8

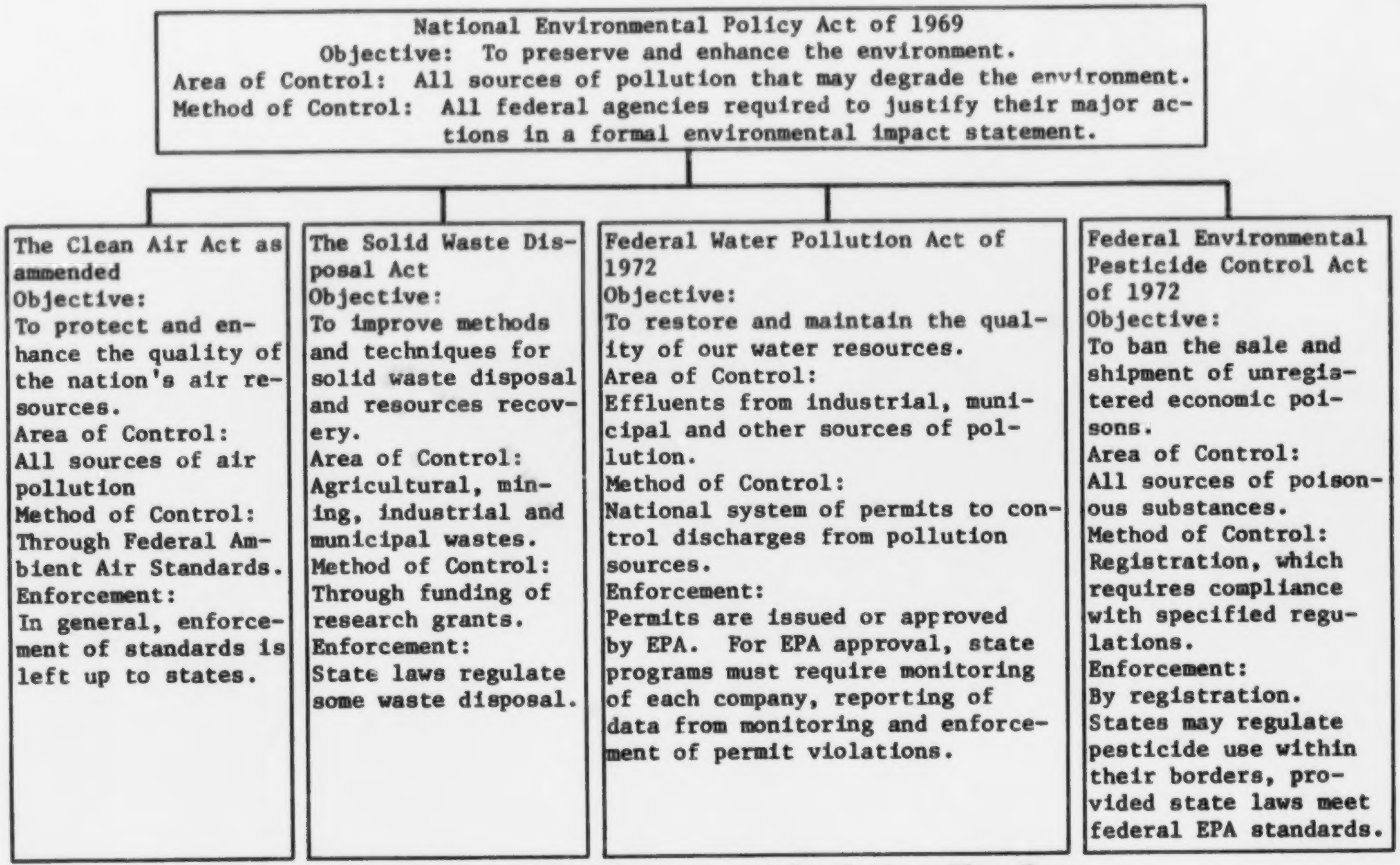
REGULATION ASSESSMENT

Many existing laws and regulations are related to hazardous and potentially hazardous substances that could affect the quality of our environment. The objectives of these laws are, in general, to improve the quality of the environment and to protect it from further pollution by establishing national standards. Some of these laws are related to disposal of waste products, however, no laws or regulations were found to directly govern the disposal or storage of hazardous waste products in underground salt deposits and/or mined openings.

The approach to determining what Federal and State laws and regulations may apply to governing the handling and storing of hazardous waste materials was to first review the Federal statutes and then identify those laws relating to the different forms of waste products and hazardous and poisonous substances. The state statutes were then reviewed to determine which states have laws and regulations that relate to the Federal standards.

The Federal government has passed many laws and regulations to cover most possible forms of pollution to our environment. Some of these statutes and subsequent standards apply to hazardous waste products that could effect the environment. The Federal acts that fall within the scope of this study and apply to hazardous waste disposal or storage are: the Clean Air Act, The Solid Waste Disposal Act, The Federal Water Pollution Act of 1972, and the Federal Environmental Pesticide Control Act of 1972. The Federal agencies responsible for administering these acts must justify major actions under the National Environmental Policy Act (NEPA) of 1969. These five major acts, their objectives, areas and methods of control, and provisions for their enforcement are summarized in Figure 22. The NEPA requires that the standards for all federal statutes relating to governing pollution to the natural environment be approved or established by the Environmental Protection Agency (EPA). This requirement along with the environmental impact statement provide the EPA with some control over substances which may be hazardous to the natural environment. However, the EPA's only method of enforcement is apparently through their standards and specified regulations for handling and enforcement through other federal statutes and agencies. The only

FEDERAL STATUTES AND REGULATIONS FLOW CHART



National Environmental Policy Act of 1969
Objective: To preserve and enhance the environment.
Area of Control: All sources of pollution that may degrade the environment.
Method of Control: All federal agencies required to justify their major actions in a formal environmental impact statement.

The Clean Air Act as ammended
Objective:
To protect and enhance the quality of the nation's air resources.
Area of Control:
All sources of air pollution
Method of Control:
Through Federal Ambient Air Standards.
Enforcement:
In general, enforcement of standards is left up to states.

The Solid Waste Disposal Act
Objective:
To improve methods and techniques for solid waste disposal and resources recovery.
Area of Control:
Agricultural, mining, industrial and municipal wastes.
Method of Control:
Through funding of research grants.
Enforcement:
State laws regulate some waste disposal.

Federal Water Pollution Act of 1972
Objective:
To restore and maintain the quality of our water resources.
Area of Control:
Effluents from industrial, municipal and other sources of pollution.
Method of Control:
National system of permits to control discharges from pollution sources.
Enforcement:
Permits are issued or approved by EPA. For EPA approval, state programs must require monitoring of each company, reporting of data from monitoring and enforcement of permit violations.

Federal Environmental Pesticide Control Act of 1972
Objective:
To ban the sale and shipment of unregistered economic poisons.
Area of Control:
All sources of poisonous substances.
Method of Control:
Registration, which requires compliance with specified regulations.
Enforcement:
By registration.
States may regulate pesticide use within their borders, provided state laws meet federal EPA standards.

Figure 22. Federal Statutes and Regulations Flow Chart.

method for enforcement found in the four areas of this review is through the Federal Water Pollution Act, where EPA permit approval requires industry to report their monitoring data and states to enforce compliance with the permits, backed by "substantial" civil and criminal penalties.

All of the states have air and water pollution laws, and most have solid waste and pesticide laws as shown in Table 17. A detailed study of each of these laws and regulations is beyond the scope of our review, however, many of these statutes have been ammended to comply with Federal standards.

In addition to the above statutes and regulations, the Federal Metal and Nonmetallic Mine Safety Act (30 U.S.C. 725) provides some standards to protect miners from hazardous materials stored in the mines. These safety standards relate to the storage of hazardous solids, liquids, and gaseous materials that are generally used in the mining operations and possibly could be applied to waste products. These specific regulations are:

30 CFR, Chapter 1
Part 57
Underground Mines

57.16 Materials storage and handling.

General Surface and Underground

57.16-3 Mandatory. Materials that can create hazards if accidentally liberated from their containers shall be stored in a manner that minimizes the dangers.

57.16-4 Mandatory. Hazardous materials shall be stored in containers of a type approved for such use by recognized agencies; such containers shall be labeled appropriately.

57.16-12 Substances that react violently or liberate dangerous fumes when mixed should be stored in such a manner that they cannot come in contact with each other.

In general, federal control of the storage and/or disposal of hazardous waste products in mines or underground salt deposits to protect our environment is a relatively new concept resulting from the NEPA. A proposed Hazardous Waste Management Act of 1973 was introduced in the U.S. Senate and in the U.S. House of Representatives to provide Federal regulation in the treatment and disposal of certain hazardous wastes. Both the Senate and the House have referred this proposal to committees where it is still in the legislative process.

This review found many laws and regulations related to hazardous substances, however, none of these statutes appear to apply directly to controlling the storage and management of hazardous waste in underground

Table 17. STATES HAVING ENVIRONMENTAL STATUTES AND REGULATIONS

	Air Pollution		Pesticides		Solid Wastes		Water Pollution	
	Laws	Regulations	Laws	Regulations	Laws	Regulations	Laws	Regulations
Alabama	X	X	none found	X	X	X	X	X
Alaska	X	X	none found	none found	X	X	X	none found
Arizona	X	X	X	X	none found	X	X	X
Arkansas	X	X	X	X	X	X	X	X
California	X	X	X	X	X	X	X	X
Colorado	X	X	X	X	X	X	X	X
Connecticut	X	X	X	X	X	X	X	X
Delaware	X	X	X	X	X	X	X	X
Florida	X	X	X	X	X	X	X	X
Georgia	X	X	X	X	X	X	X	X
Hawaii	X	X	X	X	X	X	X	X
Idaho	X	X	X	X	none found	X	X	X
Illinois	X	X	X	X	X	X	X	X
Indiana	X	X	X	X	none found	X	X	X
Iowa	X	X	X	X	X	X	X	X
Kansas	X	X	X	X	X	X	X	X
Kentucky	X	X	X	X	X	X	X	X
Louisiana	X	X	X	X	X	X	X	X
Maine	X	X	X	X	X	X	X	X
Maryland	X	X	X	X	X	X	X	X
Massachusetts	X	X	X	X	X	X	X	X
Michigan	X	X	X	X	X	X	X	X
Minnesota	X	X	X	X	X	X	X	X
Mississippi	X	X	X	X	none found	X	X	X

Table 17 (continued). STATES HAVING ENVIRONMENTAL STATUTES AND REGULATIONS

	Air Pollution		Pesticides		Solid Wastes		Water Pollution	
	Laws	Regulations	Laws	Regulations	Laws	Regulations	Laws	Regulations
Missouri	X	X	X	X	X	X	X	X
Montana	X	X	X	X	X	X	X	X
Nebraska	X	X	none found	none found	X	X	X	X
Nevada	X	X	X	X	X	X	X	X
New Hampshire	X	X	X	X	X	X	X	X
New Jersey	X	X	X	none found	X	none found	X	X
New Mexico	X	X	X	X	X	X	X	X
New York	X	X	X	X	X	X	X	X
North Carolina	X	X	X	X	X	X	X	X
North Dakota	X	X	X	X	X	X	X	X
Ohio	X	X	X	X	X	X	X	X
Oklahoma	X	X	X	X	X	X	X	X
Oregon	X	X	X	none found	X	X	X	X
Pennsylvania	X	X	X	X	X	X	X	X
Rhode Island	X	X	X	X	X	X	X	X
South Carolina	X	X	X	X	X	X	X	X
South Dakota	X	X	X	X	X	X	X	X
Tennessee	X	X	X	X	X	X	X	X
Texas	X	X	X	X	X	X	X	X
Utah	X	X	X	X	X	X	X	X
Vermont	X	X	X	X	X	X	X	X
Virginia	X	X	X	X	X	X	X	X
Washington	X	X	X	X	X	X	X	X
West Virginia	X	X	X	X	X	X	X	X
Wisconsin	X	X	X	X	X	X	X	X
Wyoming	X	X	X	X	X	X	X	X

mine openings. There is a need for legislation to provide guidelines for controlling the handling, transportation, storage, and management of hazardous wastes in underground mines on a long-term basis in order to protect our environment for future generations.

SECTION 9

MINE DESIGN

The concept of long-term storage of hazardous industrial wastes in underground mines appears feasible and might be preferred to surface storage for several important reasons. Among these are:

1. It is well protected.
2. It provides permanent, very-long term containment.
3. Valuable surface area is not used.
4. It provides good security and control of access.
5. It requires a minimum of maintenance.
6. Storage space can be continuously expanded.
7. There is less chance of damage to the environment in case of a spill.
8. The facility could possibly be designed to survive a nuclear blast.
9. It is protected from the ravages of the weather.
10. A nearly constant temperature exists underground.
11. Humidity would not vary excessively.
12. The waste would be out of sight.
13. It is less subject to sabotage.

There are many different types of mines existing today that have been excavated using numerous mining methods. Of the many mining methods in use, the room and pillar method appears to be best suited to the storage of wastes underground. The room and pillar method consists of mining a number of parallel rooms (drifts) in the formation and connecting them by means of another series of parallel rooms (crosscuts) mined at right angles to them. The room and pillar mining method is generally reserved for deposits that can be mined nearly horizontal.

Some advantages of the room and pillar mine as opposed to other types that could be used for hazardous waste disposal include:

1. The mine layout is usually near horizontal or has a low dip with the underground workings generally all on one level. In most cases the grade is shallow enough to permit the use of rubber tired equipment.

2. The rooms are generally large.
3. Large equipment can be used if required to handle heavy or bulky loads.
4. The mine is relatively simple to excavate.
5. The mining plan provides for considerable flexibility in overall layout.
6. Mine ventilation is simplified.
7. Mine haulage is simplified.

Room and pillar mines have been and can be excavated in several different types of rock. Rock types that might be suitable for the safe underground storage of hazardous industrial wastes are: salt, shale, limestone, dolomite, gypsum, potash, and granite.

IMPORTANT FACTORS TO BE CONSIDERED IN THE DESIGN OF A HAZARDOUS WASTE STORAGE FACILITY

There are numerous factors which are important in the design of a hazardous waste storage facility in rock. Many of these optimal design criteria would apply no matter what type of mine or rock formation the facility was constructed in. Some of the more important factors to consider are listed below:

Public Acceptance

1. The public must be informed of the need for a facility.
2. Public hearings should be conducted both during and after an information and education program is conducted.
3. The general public, politicians, owners and operators of mines, and land owners must be convinced that a proposed facility in a given area is in their best interest as well as in the nation's best interest.
4. A public information program should be a continuing thing during design, construction, and operation of such a facility.

Geological Factors

1. Depth from the surface to a suitable rock formation.
2. The type and character of the formation at the mining interval.
3. Formation thickness in the storage zone.
4. Permeability and porosity of the formation in the storage zone. It is preferable that the rock be dry.
5. Chemical characteristics of the formation in the storage zone. The hazardous waste must not react adversely with the rock.
6. The character of the rock above the storage zone.
7. The local citizenry should agree to construction of a hazardous industrial waste storage facility in their area.
8. The mine must have two shafts in order to comply with safety codes.
9. Adequate ventilation must be provided to the underground facility.

10. The site must be accessible to transportation facilities suitable for handling the anticipated volumes and types of hazardous waste to be stored.
11. It should be possible to construct relatively large rooms in the rock formation selected. This is necessary in order that large equipment and possibly large waste containers could be handled underground.
12. The site should be provided with an adequate supply of labor, water, and power.
13. The storage operation must not conflict with any other operations such as oil and gas wells, and other mines.
14. The total quantity of waste to be stored and the rate at which it must be accepted by the storage facility must be known. Those factors will determine the size of the surface plant, shaft hoisting facilities, underground haulage facilities, and amount of available space.
15. Means should be provided for removing the waste in the future if requested.
16. In addition, if it is an existing mine:

    A. Management and owners of any existing mine must agree to installation of a hazardous waste facility on their property.
    B. The hazardous waste storage area must be completely isolated from the producing section of the operating mine.

DESIGN FACTORS TO CONSIDER FOR AN IDEAL STORAGE FACILITY

There are several other design factors that, if complied with, would result in a more ideal underground hazardous waste storage facility. These are:

1. It should be a room and pillar mine.
2. It is an operating mine with large mineable reserves.
3. The prospects for continued operation of the mine and marketing of the product are excellent.
4. The rock be essentially homogeneous.

HANDLING AND PLACEMENT OF HAZARDOUS WASTES

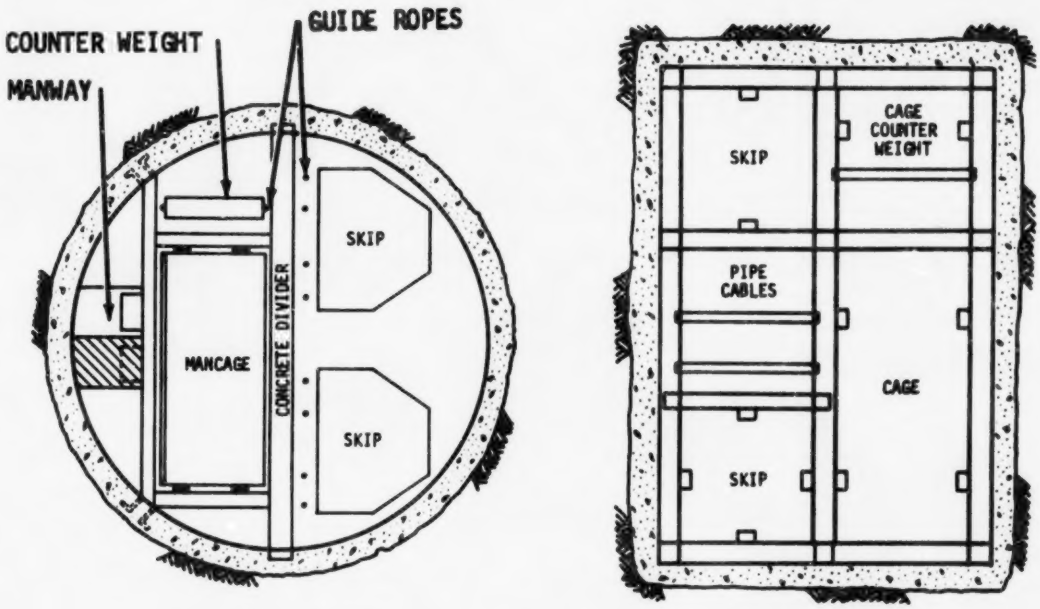
Hazardous waste products can be stored in existing mines, both active and inactive, or in new mines developed principally for hazardous waste storage. In order to convert these mines into waste storage facilities, many problems will have to be overcome and many basic requirements met. It is possible that the surface facilities could be quite extensive. Safe access to the underground workings must be provided. In addition, the underground facilities must be adequate to handle the type and volume of waste stored. Irrespective of what type of mine is selected, they will all have several requirements in common. Most of the surface handling facilities for hazardous waste will be the same, as will be the facilities for transporting the hazardous waste from the surface to underground, and once underground, to its final resting place. The more important necessary facilities that would be common to all types of storage sites are listed below.

Subsurface Facilities Required

1. Unloading the loading equipment to handle the waste as it is received. This equipment must be capable of handling the container sizes and waste volumes anticipated.
2. Possible surface sorting, processing, repackaging, and storage facilities would be required. It may be more economical to ship some wastes in large bulk tanks and then, once at the storage site, repackage them permanently im smaller sealed containers.
3. Decontamination facilities for men and equipment in case of a spill.
4. Mine ventilation facilities consisting of large surface installed fans.
5. Filters to clean the ventilation air as it is exhausted from the mine if necessary.
6. First aid station.
7. Standby electric generators in case of a power failure.
8. Continuous environmental monitoring system.

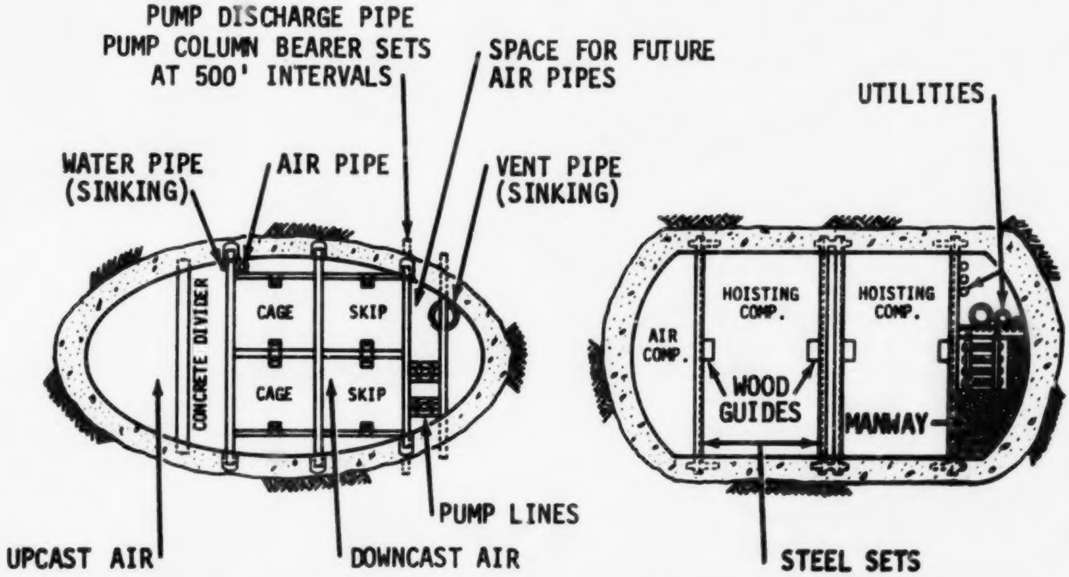
Facilities Required For Underground Access

1. Vertical or inclined shaft. The shaft configuration can be either circular, oval, eliptical, or rectangular. The circular shaft is the strongest configuration and is preferred if the shaft is to be sunk through heavy ground and/or it is to be concrete lined. Figure 23 illustrates various shaft configurations which are possible.
2. Under certain conditions it may be preferable to gain access to the mine via an inclined slope. The slope could be either a straight ramp or a spiral ramp and driven on a shallow grade so that it could be negotiated by rubber tired vehicles. An inclined slope might be suitable for entry into a mine located close to the surface. An advantage would be that waste containers would be transported by the same conveyance between the surface and underground storage cell. This would eliminate multiple handling.
3. A minimum of two separate shafts or entries are required to conform with applicable USBM safety regulations and provide adequate ventilation to the underground workings.
4. It is possible that in some instances, access to the mine could be through a tunnel driven into the side of a hill. In this case, waste could be hauled into the mine using a train or wheeled vehicles.
5. If a vertical or near vertical shaft is used it must be designed to


COUNTER WEIGHT
GUIDE ROPES
MANWAY
SKIP
MANCAGE
CONCRETE DIVIDER
SKIP
CAGE COUNTER WEIGHT
SKIP
PIPE CABLES
CAGE
SKIP

CIRCULAR SHAFT

RECTANGULAR SHAFT


PUMP DISCHARGE PIPE
PUMP COLUMN BEARER SETS AT 500' INTERVALS
SPACE FOR FUTURE AIR PIPES
WATER PIPE (SINKING)
AIR PIPE
VENT PIPE (SINKING)
CONCRETE DIVIDER
CAGE
SKIP
CAGE
SKIP
PUMP LINES
UPCAST AIR
DOWNCAST AIR
UTILITIES
AIR COMP.
HOISTING COMP.
HOISTING COMP.
WOOD GUIDES
MANWAY
STEEL SETS

ELLIPTICAL SHAFT

ELLIPTICAL SHAFT, MODIFIED

Figure 23. Shaft Configurations.

handle the anticipated waste volumes and container sizes. The headframe and hoist must be designed to lower heavy loads. This could require specially designed hoist brakes and controls as conventional hoists are designed to lift rather than lower heavy loads.

6. The shaft conveyance or cage must be designed to handle special shaped waste containers and heavy loads.
7. The shaft conveyance must also be designed to safely transport men and heavy equipment into and out of the mine.
8. An emergency hoist and man cage should be provided so that men could be removed from the mine or shaft in case the main hoist failed. It should be connected to an emergency power supply.

Basic Underground Facilities And Equipment Required For A Hazardous Waste Storage Operation

1. Heavy equipment to unload, haul, and place the hazardous waste storage containers in their isolated storage cells. This equipment should be rubber tired for increased flexibility and maneuverability and especially designed to pick up, move, and place the storage containers.
2. A decontamination station of men and equipment must be provided in case of a spill of hazardous waste. Provision must be made to dispose of any cleanup waste products.
3. An air quality monitoring system must be installed in the return air passages. It should be possible to remotely monitor the underground environment to determine if any waste product is escaping from the facility. The remote monitoring systems should have built-in alarms to both visually and audibly alert underground and surface personnel.
4. A rock stability monitoring system should be provided in order to verify the long-term stability of the underground structures. This monitoring system could consist of rock extensometers, both manual and readout types, and single and multiple position. The extensometers should be installed in critical areas to measure roof sag, floor heave, and closure between pillars and between the roof and floor. If required, the rock mechanics instrumentation could be monitored remotely at a surface station.
5. A fully equipped first aid station, manned at all times by fully qualified personnel, will be required underground.
6. Ventilation booster fans may be required underground; depending on the size and complexity of the facility. The facility must be designed so that men are always working in fresh air. The storage cells containing waste must be isolated to prevent personnel exposure to air passing through them. It will probably be necessary to install some stoppings, or barriers, in order to control the direction of the ventilation air. A considerable number of stoppings would probably have to be installed in an existing mine.
7. An underground repair shop must be provided for maintaining heavy equipment that cannot be easily returned to the surface. An overhead crane should be included.

8. Maintenance equipment will be required underground. At times it will be necessary to clean up loose rock from falls, install additional rock bolts, and grade the roadways.
9. If any water is entering the mine it must be collected and pumped to the surface. If the water becomes contaminated with waste products, it will be necessary to provide handling and treatment facilities.
10. Fire fighting equipment must be provided underground in strategic locations. It must be of adequate size to handle any possible fire that might occur.
11. Adequate bulkheads to separate the intake shaft from the return air shaft must be provided.

EVALUATION OF EXISTING AND NEW MINES AS STORAGE SITES

There are three categories of mines that can be considered for hazardous industrial waste storage. These are: active existing mines, inactive existing mines, and new mines designed specifically for hazardous waste storage. Due to the continuing production of these wastes, the ideal solution for emplacement of hazardous waste in mines is to obtain a portion of an operating mine because an operating mine is continually creating more space. This concept, however, will require public acceptance and industry concurrence. A generalization of an existing room and pillar mine is illustrated in Figure 24. This Figure shows several of the many room and pillar layouts that now exist. Less desirable solutions are the use of inactive mines or creating new mines. Listed below are some of the more important advantages and disadvantages of existing, inactive, and new mines as storage sites.

Existing Mines As Waste Storage Sites

Advantages--

1. The space is already available. In some cases, only minor amounts of underground cleanup and rock stabilization will be required.
2. New storage space is continually being developed for as long as the mine is in operation.
3. This type of storage should be less expensive than utilizing either an inactive mine or a new mine.
4. There would be a labor pool experienced in mining operations in the area.

Disadvantages--

1. The waste storage area must be isolated from the working section of the mine by constructing concrete bulkheads. This would prevent possible contamination of the mine and the product being mined. Bulkhead construction costs could be quite large depending on the

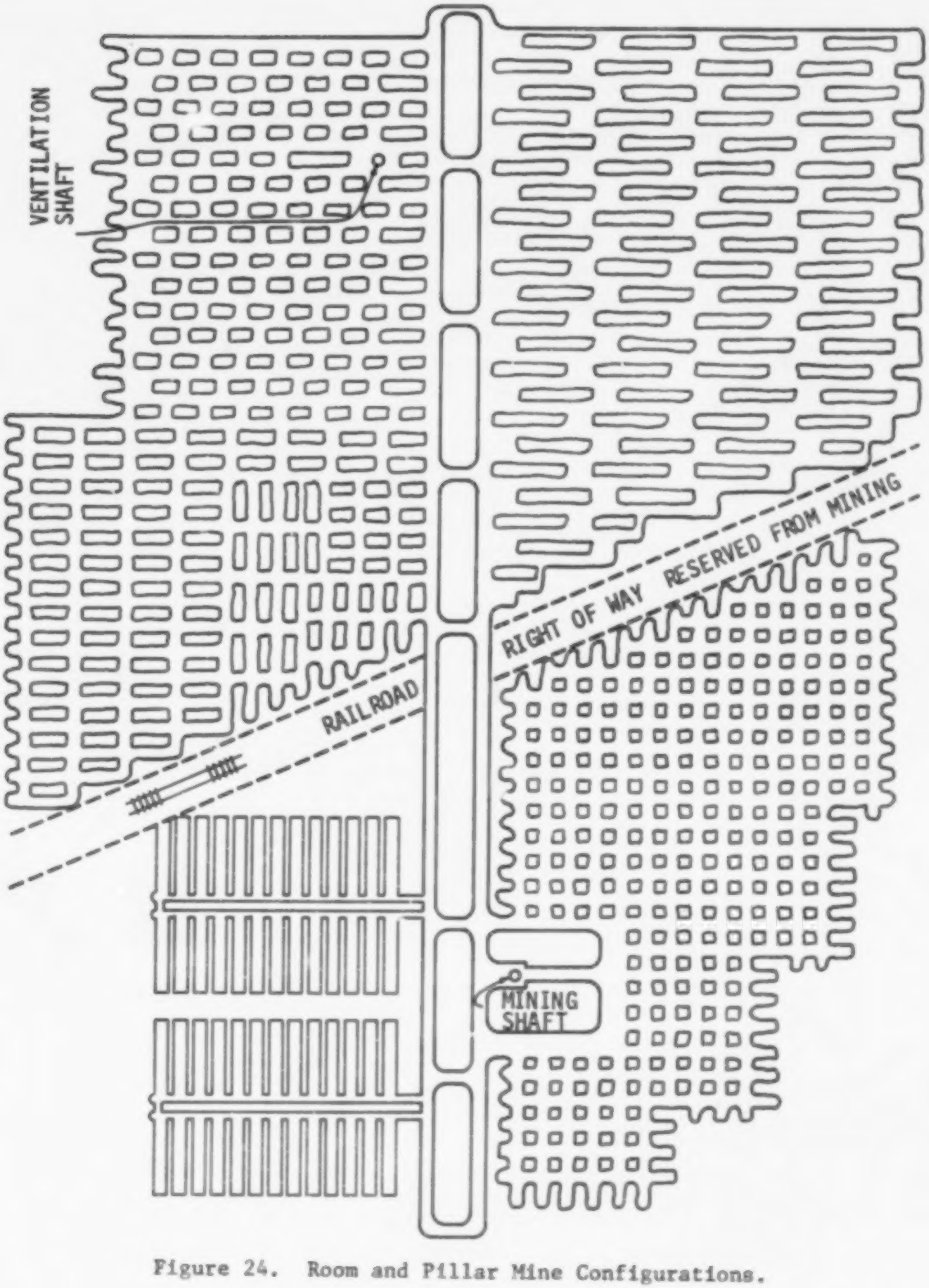

VENTILATION SHAFT
RIGHT OF WAY RESERVED FROM MINING
RAILROAD
MINING SHAFT

Figure 24. Room and Pillar Mine Configurations.

number of bulkheads required and their design requirements.

2. The long-term stability of the section already mined may not be good. This would be due to a high extraction ratio and desire to maximize productivity, and could result in extensive remedial ground support which may not be adequate over a long period.
3. The layout of the section already excavated may be far from ideal from a hazardous waste storage standpoint. This would result in extensive new mining and/or loss of storage volume.
4. It would probably be necessary to sink new shafts. It may not be possible to do this in the most ideal location due to the requirement for leaving a substantial pillar around the shaft.

Inactive Mines As Waste Storage Sites

Advantages--

1. Would not interfere with the operations of an active mine.
2. Construction of bulkheads necessary to separate the active mining operations from the storage area would not be required.
3. It might be possible to use the existing access shafts. If so, this could result in a substantial reduction in total costs for converting the mine to waste storage.
4. The waste storage operation would not conflict in any way with active mining operations.
5. The inactive mine, if sufficiently large and located in the right area, could accommodate a particular hazardous waste at its current rate of production for a very long time.

Disadvantages--

1. A considerable amount of cleanup and repair of the inactive mine may be required.
2. The mine may not have enough usable space to contain the volume of hazardous waste anticipated to be generated over a long period of time.
3. An older, inactive mine may be less stable due to high extraction ratios used while mining.
4. The mine could be partly or completely flooded with water, thus requiring expensive dewatering.
5. Original power and railroad facilities may have been removed from the site.
6. Engineering data such as detailed mine plans and maps may have been lost. This could result in an extensive remapping of the mine.

New Mines As Storage Sites

New mines as sites for hazardous waste storage can be broken down into two basic categories:

1. The mining of an economical mineral commodity occurring con-

currently with the storage of hazardous waste. An agreement is made with a mining company whereby it develops a new mine in an area suitable for waste storage. The intent is that a mineral commodity, such as salt or potash, could be mined profitably while, at the same time, space for hazardous waste storage is being created. The mine would be developed in such a manner as to optimize the waste storage facility configuration.

2. Storage space is mined in waste rock having little or no economic value. The waste rock may or may not be sold as fill material, etc. An example of this type of facility would be one mined in shale, limestone, or granite.

Figure 25 illustrates one concept for a new mine that could be developed as a storage facility. First it is necessary to completely mine out one block or a quarter of the first area involved. Then, while the mining of the second block takes place, hazardous wastes can be stored in the block already excavated. Once the original 4-block storage facility has been completed, a second 4-block storage facility could be constructed adjacent to the first, and so on.

Advantages--

1. The mine can be designed specifically for the storage of hazardous waste.
2. The mine could be designed to be as stable as necessary in order to provide for very long-term storage.
3. There would be essentially no limit to the volume of storage space that could be developed.
4. There would be considerable flexibility in locating the hazardous waste storage facility. It could be located in a central location most favorable to the source of waste provided a suitable rock formation could be located.

Disadvantages--

The overall mining costs would probably be greater than those incurred by using an existing, operating mine. In the case of a mine producing a profitable mineral commodity, more of it would have to be left in the ground due to a lower extraction ratio. If mining space only with no chance to sell the material mined, costs will be obviously higher and, therefore, the storage costs will be greater.

OPERATION OF A FACILITY

The operation of the underground storage facility will require close control and monitoring of all phases of waste handling from the time the waste is received until it is safely stored underground. Strict attention must be given to personnel and environmental safety. It will be

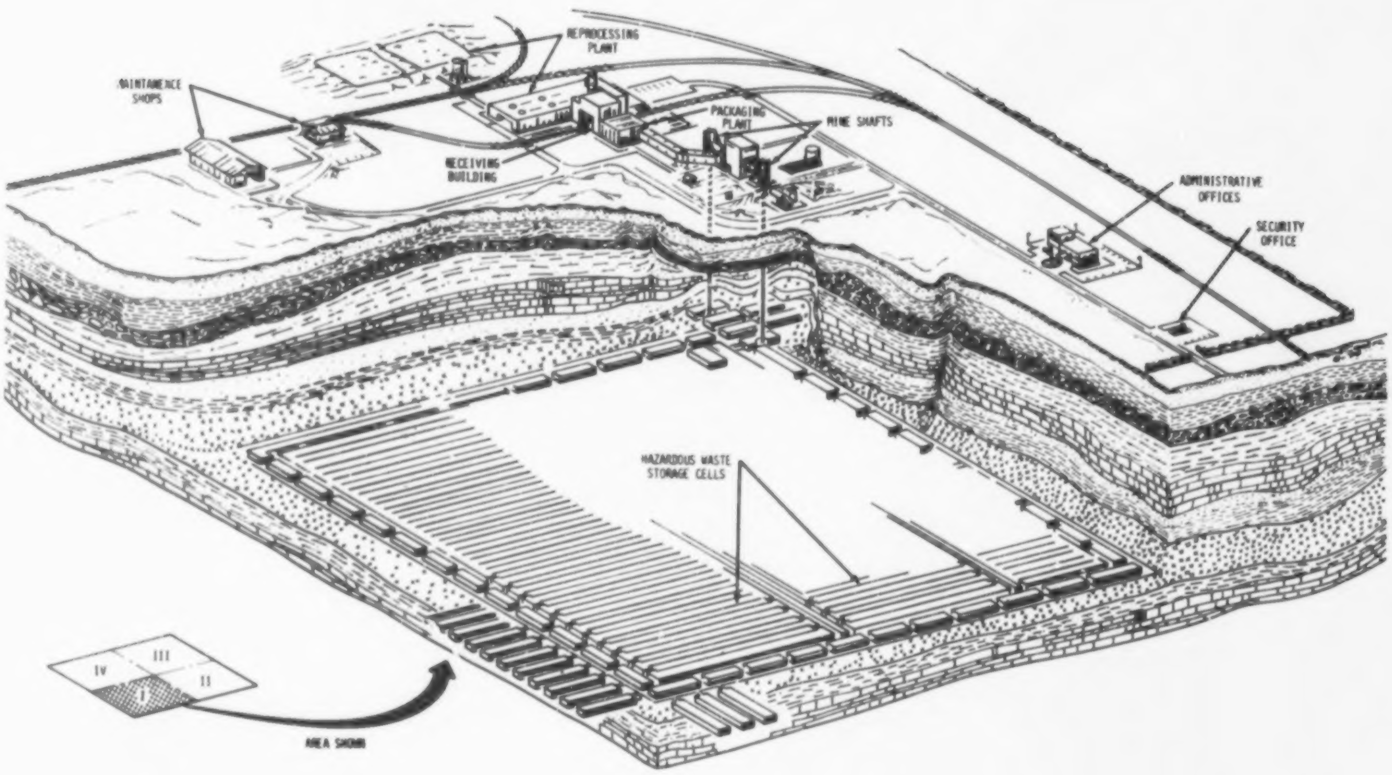

MAINTANENCE SHOPS
REPROCESSING PLANT
RECEIVING BUILDING
PACKAGING PLANT
MINE SHAFTS
ADMINISTRATIVE OFFICES
SECURITY OFFICE
HAZARDOUS WASTE STORAGE CELLS
IV
III
I
II
AREA SHOWN

Figure 25. Conceptual View of Mine Storage Facility.

necessary to provide for the remote and continuous monitoring of all critical systems both above and below ground.

Manpower Requirements

In order to achieve these goals, a staff of adequately trained people will be required. The staff will probably be somewhat heavy in technical and supervisory oriented personnel. An attempt to quantify the various labor classifications has been made. It must be realized, however, that these recommended manpower requirements could vary considerably depending on such factors as the size of the facility, final facility design, facility location, type of waste to be stored, local union regulations, etc.

It is anticipated that the site manager would include among his staff personnel, a health and safety specialist having at lease one assistant and also an instrument technician to help install and service the remote monitoring equipment. This department could also be responsible for monitoring the rock mechanics instrumentation, and would monitor and maintain the mine ventilation system. There would also be an office staff who would be responsible for inventory control. Reporting to the manager, a facility superintendent would supervise the facility security force, the storage foreman, the preparation and cleanup foreman, and the maintenance foreman.

The storage foreman would be in charge of those personnel directly involved in handling the waste from its arrival at the site until it is safely in its final resting place underground. He would be in charge of the material handling specialists who unload the waste when it arrives, transport it to the shaft, incline slope or tunnel and then unload it underground. He would also supervise the hoistman, the shaftman (top lander), the surface and underground transporter operators, and the underground storage specialists who oversee waste placement in the correct storage cells underground.

The preparation and cleanup foreman would be in charge of the preparation and cleanup crew whose duties would include:

1. Cleaning up the storage area and preparing it for waste.
2. Cleaning up falls of rock from the roof and ribs.
3. Stabilizing the roof and pillars by installing rockbolts, steel mesh, etc.
4. Installing ventilation stoppings (bulkheads).
5. Cleaning up spills of toxic waste.

The maintenance foreman would be responsible for the maintenance crew whose duties would include grading the underground roadways and maintaining the underground and surface equipment and facilities.

Waste Handling Procedure

The overall operation of the storage facility must be well planned and coordinated. The more important operations of a hypothetical hazardous waste storage facility is described in order to point out key operations.

The waste material, as received at the storage site, may be in a storage container and a form suitable for final storage. On the other hand, it may be more economical to ship the waste in large, bulk tank cars to the storage site where it would then be transferred to smaller containers for permanent underground storage. Economics or other conditions may also dictate that some of the waste products be reprocessed at the storage site prior to being permanently containerized and stored. These are variables that would have to be considered in the final design of a hazardous waste storage facility.

Once the waste has been received at the site, careful inventory controls must be maintained at all times. This is necessary in order to keep close check on the waste reprocessing and recontainerizing, if any, and to verify that each given waste product is stored in the proper storage cell underground. Figure 26 is a flow diagram which illustrates the possible waste handling steps. The health and safety staff would monitor the waste handling processes from the time the waste arrives at the site until it is safely stored underground.

The permanent storage containers should be as large as is feasible and economical to handle above and below ground. The maximum container size will be largely controlled by the size of the access shaft, inclined slope or tunnel, capacity of the equipment used to transport the waste underground, and the size of the underground excavation. More than likely it will be advantageous to design and build special transporters for moving the storage containers on the surface and underground.

If access to the underground workings is through an inclined ramp or horizontal tunnel, it would be possible to use a rubber tired transporter to carry the waste containers from the surface directly to its storage cell underground. In the case of a tunnel, a train could also be used to transport the waste underground. If access to the mine is through a vertical shaft, the headframe, hoist, and shaft conveyance must be designed to safely handle the weight and configuration of the waste containers. The braking system on the hoist must be designed to lower heavy loads. Normally a hoist is designed to lift heavy loads. If men are to ride in the shaft for access to the underground workings, the shaft conveyance (man cage) must be equipped with a safety dog mechanism. The safety dogs are designed to stop the man cage in the shaft should the connection between the cage and the hoist break.

If the waste is lowered down a vertical shaft, provision must be made to transfer the containers from the shaft conveyance to the underground transporter. It will be necessary to install a monorail having an

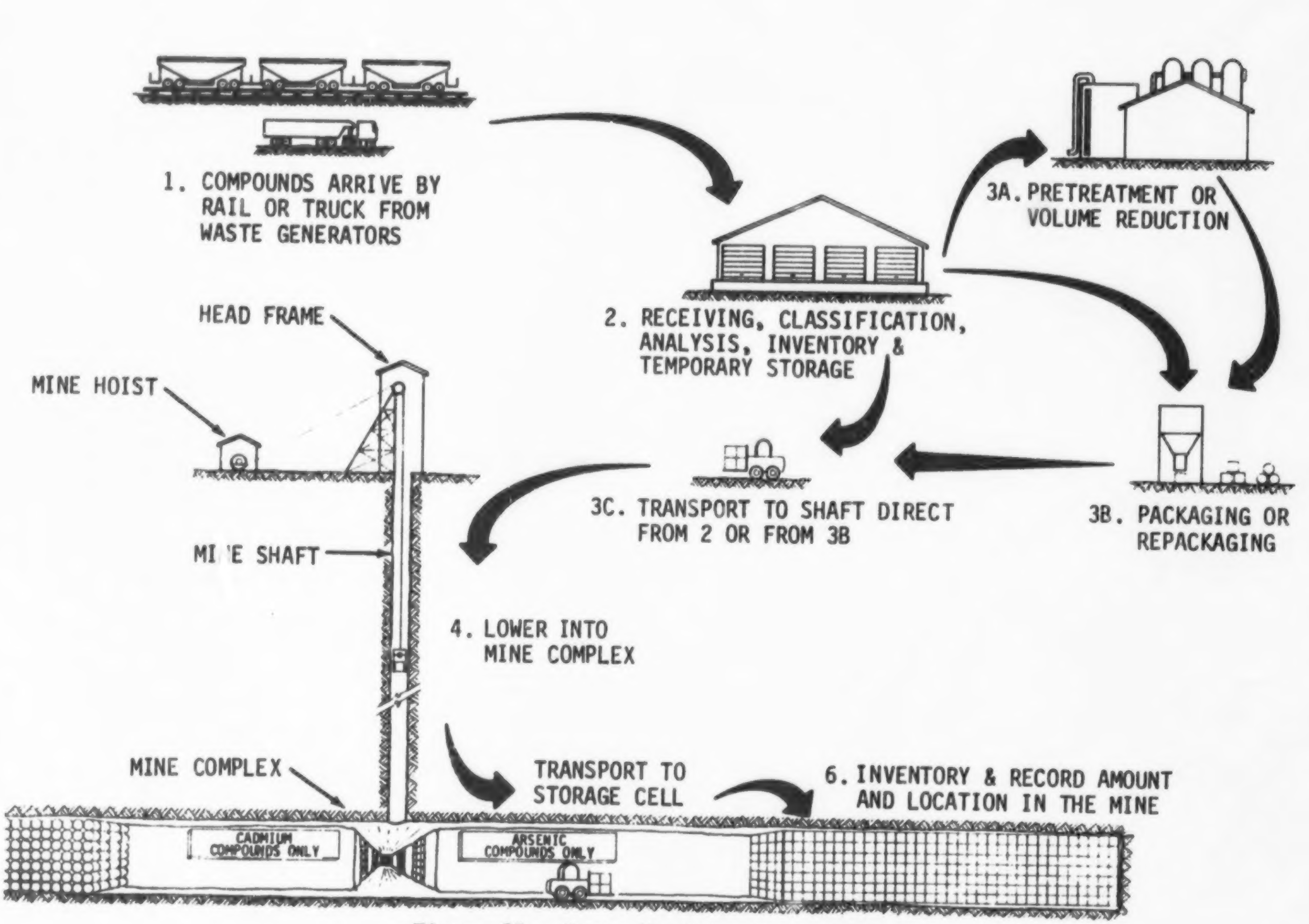

1. COMPOUNDS ARRIVE BY RAIL OR TRUCK FROM WASTE GENERATORS
2. RECEIVING, CLASSIFICATION, ANALYSIS, INVENTORY & TEMPORARY STORAGE
3A. PRETREATMENT OR VOLUME REDUCTION
3B. PACKAGING OR REPACKAGING
3C. TRANSPORT TO SHAFT DIRECT FROM 2 OR FROM 3B
HEAD FRAME
MINE HOIST
MINE SHAFT
4. LOWER INTO MINE COMPLEX
MINE COMPLEX
TRANSPORT TO STORAGE CELL
6. INVENTORY & RECORD AMOUNT AND LOCATION IN THE MINE
CADMIUM COMPOUNDS ONLY
ARSENIC COMPOUNDS ONLY

Figure 26. Waste Handling Flow Chart.

electric hoist in the shaft station to handle heavy equipment and supplies, and possibly waste containers.

Once the waste containers are unloaded at the underground shaft station, they can be hauled by a rubber tired transporter to their respective storage cells. Throughout this operation, careful inventory control is necessary in order to ascertain that the waste containers are handled and stored properly.

Preparation Of Storage Cells For Permanent Waste Retention

Before the waste can be placed in a storage cell underground, the area must first be prepared to permanently receive the waste. This would be the responsibility of the preparation and cleanup crew. The crew would repair and mark roadways into the area and bar down any loose rock from the roof and the pillar ribs. If required, the roof and ribs would be stabilized by installing rock bolts, steel mesh, shotcrete, concrete, or some other form of permanent rock support.

The preparation and cleanup crew would also be responsible for installing both temporary and permanent ventilation stoppings (bulkheads). These are necessary in order to direct sufficient volumes of ventilation air into the working areas of the mine. The location of the temporary stoppings would have to be changed as working conditions warranted it. This crew would also install the required ventilation booster fans and ventilation ducts underground.

Should a spill of waste occur, the preparation and cleanup crew would clean up and decontaminate the area and equipment. Therefore, it will be necessary to construct a decontamination room underground where men, equipment, and materials could be decontaminated.

Health And Safety Environmental Monitoring

It will be the responsibility of the health and safety staff to see that the health and safety of the work force and people in the surrounding area is secure, and that the environment is protected from any toxic effects of hazardous wastes. This will require setting up and maintaining an adequate safety program that would be mandatory for all employees to attend. It would require sensitive sensing devices be installed on the surface and underground that could be remotely controlled and would monitor the air and water for toxic substances. These sensing instruments should be designed to record the data being measured as well as sounding an audible and visual warning signal when safe limits have been exceeded.

Rock mechanics instrumentation should also be installed in all critical areas underground. This could be in the form of single and multiple position extensometers, both manual and remote readout types, and devices for measuring the rate of closure between the roof and floor and between adjacent pillars. More sophisticated rock mechanics instrumentation and measurements would be utilized if necessary.

The health and safety staff would also have to be prepared to repair and replace, if necessary, the health and safety monitoring instrumentation. It would also be the responsibility of the health and safety staff to train and maintain a mine rescue crew. This crew would be on call at all times in case of an underground disaster such as a fire, explosion, cave-in, etc. and could include mine workers.

In some instances it might be necessary to drill vertical wells around the storage area for verifying that toxic substances were not escaping from the storage facility and contaminating the ground water supply. The health and safety staff would be responsible for monitoring these wells.

Maintenance Of The Storage Facilities

A maintenance staff will be required to service equipment. This will require maintenance shops to be constructed both on the surface and underground. The underground shop would service that equipment too large to be easily transported to the surface for repairs. The underground shop must be large encough to service the waste container transporter. An overhead crane will be required in the underground shop to handle heavy loads.

The maintenance staff would maintain all of the surface equipment and facilities. This would include the hoists, headframes, electric generator sets, compressors, surface container transporter, and all other vehicles and equipment. They would also be responsible for maintaining the surface installed ventilation fans and associated equipment. In addition, the maintenance staff would be responsible for maintaining all access roads on the surface and underground.

Site Security

A site security staff would be required in order to control access to the storage site, both during working hours and when the facility is closed. Whenever a site is closed, for instance during a weekend or at night, the security staff would also water the remote monitoring health and safety equipment. If an alarm was sounded, the site superintendent or site manager could be alerted and the necessary remedial action commenced.

SUMMARY

There are several factors which must be considered in the design of a hazardous waste storage facility. These factors consist of:

1. Public, political, and owner acceptance of the need
2. Geologically secure site
3. Facility design
4. Operating requirements including safety

Each of these factors have been examined and, in general, acceptable solutions can be found for any known problems which may occur.

SECTION 10

PROOF-OF-CONCEPT

In each section of this report, there are stated or inferred conclusions which were developed during the course of the investigation. The objective of proof-of-concept is to organize and present these conclusions and results, within the framework of the established criteria and definitions, to either prove or disprove the technical feasibility of storing hazardous industrial wastes in mines. A proof-of-concept approach was chosen as the best alternative to a case history study which could not be performed because no underground storage facilities of this type were found to exist in the United States.

BACKGROUND

The data which provide the basis for proof-of-concept are the results of several primary and secondary investigations into salient aspects of the underground storage problem. The primary research effort was directed toward an understanding of the basic technical questions and included geological, chemical, and geochemical investigations.

The geological investigation consisted of a physical characterization of mine areas, including the lithologic, structural, hydrologic, and seismic environments. Special emphasis was placed on those aspects considered most critical to long-term isolation of the stored wastes.

The chemical study consisted of identifying the wastes, analyzing the chemical behavior of each waste compound, determining treatment procedures to decrease the hazardous properties of each waste, screening and classifying the wastes as to hazard potential and chemical compatibility in both pure and treated forms, classifying the wastes on the basis of acceptability underground, and finally determining the present and future volume of each hazardous waste.

The geochemical study synthesized the results of the geological and chemical investigations. The seven chosen lithologies, based on mining activity, physical occurrence, minability, and limiting and/or beneficial reactivity, were compared chemically with the waste compounds. The compatibility of each waste with each lithology was determined using a "worst-case" analysis in which the storable wastes were assumed to be in contact with host rocks under both wet and dry conditions. The resulting reactions would not be possible unless the waste containers were ruptured by some catastrophic event such as a sudden mine failure, fire, or flooding. The possibility of such an occurrence is extremely remote when all the prestorage criteria are met; however, this approach was taken to insure that every conceivable interaction which might influence waste isolation would be appraised.

The secondary studies deal with other pertinent aspects of underground waste storage which are important to an overall feasibility appraisal, but are not essential from a strictly technical standpoint. Included was a state-of-the-art review of detection, monitoring, and control technology; an assessment of present and future regulations controlling underground space; and the development of a conceptual model to illustrate the operation of a mined storage facility.

The geological investigation concluded by recommending detailed, site-specific studies of mines prior to making final recommendations of existing underground space. Within the scope of this study it was not possible to evaluate mines as rigorously as required; however, AEC sponsored investigations of the abandoned Carey salt mine at Lyons, Kansas for possible use as a radioactive waste repository, provide the types of detailed information required to make a credible proof-of-concept analysis.

PREVIOUS RESEARCH - LYONS MINE

The inactive salt mine at Lyons, Kansas was worked between 1890 and 1948. The salt was excavated from the Hutchinson member of the Wellington Formation (Permian age) from a depth of 310 meters (1,020 ft). Room and pillar mining methods were employed with openings ranging between 2.7 and 4.7 meters (9 to 14 ft) in height. The total volume of mined space is approximately 1,019.520 cubic meters (36,000,000 cubic ft), however, the utility of all the space is uncertain.

The mine area excavated prior to 1940 is described as partly deteriorated as evidenced by common floor heaves and roof falls. This area would undoubtedly require an extensive rehabilitation and clean-up in order to be made serviceable. The areas mined after 1940 at a reduced extraction ratio (75% prior to 1940 vs. 65% after 1940) are described as showing only a few minor signs of decay, primarily in the floor. Minor water leakage down the shaft has existed for many years, but was never of such magnitude as to affect the mining operation. The water problem was determined to be correctable by the mine engineers; however, the need to implement corrective action never developed.

The bedded salt mined at the Carey mine was typically 95% pure halite with minor impurities of shale, anhydrite, and water (interstitial). The anhydrite occurs as discreet zones within the salt mass, while the shales are usually found as thin bedded layers, partings, and flakes which give a dark horizontal banded appearance to the massive salt deposit. The Hutchinson salt unit is approximately 67.1 meters (202.5 ft) thick at the Lyons Mine site and is approximately 85 percent salt and 15 percent interbedded shale and anhydrite. The mined interval is overlain by some 48.8 meters (160 ft) of salt, 168 meters (550 ft) of shale, 4.6 meters (15 ft) of dolomite and 82.3 meters (270 ft) of mostly unconsolidated sand and clay. Underlying the mined openings is approximately 10.7 meters (35 ft) of salt and at least 111.2 meters (365 ft) of shale.

Significant water-bearing zones occur both above and below the salt; however, the mined interval is effectively isolated by the thick sequences of impervious salt and shale. The conclusions of the AEC study indicate that the most probable threat to the hydrologic isolation of the Lyons mine is by artificial means such as borehole penetration, or communication with nearby hydraulic and conventional mining operations. All of these factors can either be controlled, or eliminated as potential threats to the integrity of the mine.

The structural stability of the mined space was studied intensively, especially in a limited area of the mine excavated specifically for the radioactive waste study. Measurements of pillar load at a 75 percent extraction ratio indicated that these pillars were under approximately 28,270 kilonewtons per square meter (4,100 psi) while the load at a 65 percent extraction ratio was reduced to about 19,995 kilonewtons per square meter (2,900 psi) and resulted in a much more stable opening. Plastic deformation (creep), slumping, heaving, and rates of closure were measured using 700 gages, included were 60 to measure convergence, and 640 to measure strain (extensometers) variously located in the ribs, floor, and roof. Many were intended to assess the effect of heat on the structures, since radioactive wastes generate heat as they decay. At temperatures below 200°C. the transient and permanent displacements were typically very slow and predictable. Core samples tested in a laboratory at room temperature and atmospheric pressure gave preliminary compressive strength values of about 19,995 kilonewtons per square meter (2,900 psi) and tensile strengths of 2,415 kilonewtons per square meter (350 psi). This resulted in a calculated creep parameter which would allow complete closure in three years. By reducing the calculated value by a magnitude of two, the closure time increased to approximately 450 years, which correlated reasonably well with the field data.

The results of these investigations indicate that the expected life of those openings mined at the 65 percent extraction ratio is probably in excess of 400 years, and this lifespan could be readily extended by periodic expansion (remining). A second option would be to remove the waste containers, either for recycling or storage in new openings, on a periodic basis as determined by the rate of closure. It should be noted, however, that the rate of closure is a natural occurrence which can be controlled through reduced extraction ratios, structural supports, or remining which would insure long-term retrievability of the stored wastes.

The effect of heat on the salt formation was found to be significant, especially above 200°C. Plastic deformation was seen to increase with increasing heat until a temperature of 250°C. was reached at which time the interstitial water was explosively liberated. The 250°C. temperature was found to be quite constant even under varied conditions, and the explosive release was typically powerful and destructive. On the other hand, salt was also found to be a reasonably good heat sink capable of diffusing heat at a rate deemed acceptable for radioactive waste disposal. Due to the special requirements established for the storage of chemical wastes underground, heat from reactions or fire will not present a significant risk potential.

In addition to the studies of the bedded salt deposit, a qualitative analysis of the overlying shale unit was conducted. Generally, this research showed that montmorillonite and other expanding clays (smectite group) decreased with depth, while mixed-layer clays and chamosite which are less expandable increased. These shale occurrences are significant in assessing potential waste migration from a salt opening. Hydrologic studies to determine the migration potential of contaminants carried in ground water, confirmed that shale provides an excellent barrier to migration due to its low porosity and impermeability. Shales with high montmorillonite content have good potential for ion exchange, which causes these shales to trap toxic ions carried in a ground water solution thus limiting migration. In addition, expanding clays have the capacity to adsorb and hold ground water. It was found that adsorbed water commonly assumes a nonliquid state (quasi-crystalline) which acts to make water movement in confined argillaceous sediments a self-limiting function.

Results

The original conclusion of the AEC-sponsored study was that the Lyons mine was a favorable site for the long-term storage and isolation of radioactive wastes. Subsequent review, however, concluded that several potential problems associated with nearby mining operations and the proximity of the mine to several active oil fields having a high potential for future exploratory drilling were sufficient to warrant additional site studies in other areas. In short, the technical feasibility of storing radioactive waste was established, but the practicality of using the Lyons site was questionable.

COMPARISON TO WASTE STORAGE CRITERIA

A comparison can be made of the geologic, hydrologic, chemical and geochemical criteria developed for the safe storage and management of hazardous industrial wastes underground to the Lyons mine site. If a majority of the criteria can be met, it will be shown that it is technically feasible to store these wastes at this site, and by inference, at other sites meeting the established criteria.

Homogeneous Lithology

The Lyons mine is in a large bedded salt deposit with approximately 95 percent halite in the mined interval. Primary impurities are argillaceous shales occurring as thin bands plus occasional anhydrite. Though typical of bedded salt deposits, this homogeneity is rather exceptional in nature and is rated as excellent for geochemical analysis because both the number and types of reactions which could occur between the storable wastes and the salt formation would be much more predictable.

Competent

Various studies of bedded salt have shown that its strength is comparable to concrete, but with the added advantage of gradual stress release through plastic deformation. The ease of mining, plus its relatively high structural strength makes salt an excellent mining medium.

Dry and Impervious

Salt is essentially impervious to water, and due to its plasticity it tends to maintain its imperviousness by healing artificial or natural fractures. The Lyons mine is dry except for minor shaft leakage that is correctable.

Low Porosity

Salt, being crystalline, typically has very low porosity which rarely exceeds a few percent. At the Lyons mine the porosity is normally less than three percent with interstitial water filling most existing pores.

Nonfaulted

The Lyons mine has intersected no known fault displacements and for the most part the whole Permian Salt Basin in Kansas appears to be free of large scale faulting.

Isolated From Aquifers

The thick salt deposit plus the thick shale units above and below the salt effectively isolate the mine from known water bearing strata.

Widespread Distribution

The major salt deposit underlies a large portion of central Kansas.

Thick Deposit

The thickness of the Hutchinson salt at Lyons, Kansas is more than adequate for excavation. It varies locally, but is generally in excess of 60 meters (200 ft).

Low Angle Dip

The inclination of the bedded salt is uniform, and less than 3 degrees from horizontal.

Dissolution (Alteration)

Dissolution of the salt front, some 58 kilometers (36 miles) east of the Lyons mine, appears to be progressing west at a rate of 9.7 km/million years (6 miles per million years). At this rate, the suitability of the Lyons site as a storage facility would not be adversely affected.

Low Seismicity

Historic seismicity is rare and of very low magnitude. Very long tectonic stability is evident.

Slow Surface Erosion

Down cutting by surface streams is generally slow and it is expected that several million years will be required for them to reach the mine at present rates of erosion.

Glacial Advance

A study of the consequences of future glaciation indicates that the stability of the mine should not be effected.

Ocean Inundation

Should present polar ice caps melt, the subsequent rise of ocean levels would not reach the Lyons, Kansas area.

Low Surface Relief

Kansas is noted for its extremely low relief and the Lyons area is very flat.

Year-Round Access

Except for brief unusually extreme meteorologic conditions, year-round access is possible.

Low Economic Value

Salt, due to extensive occurrences, is a high-volume commodity not subject to sharp economic changes.

Mine Depth Less Than 915 Meters (3,000 ft)

The inactive Carey Mine at Lyons was mined at 310.9 meters (1,020 ft) which provides optimum conditions for both access and isolation.

Room and Pillar Design

Various room and pillar combinations were used at the Lyons mine and all are believed adaptable to fit storage configurations.

Single Level

The mine is single level, ranging from 2.7 to 4.3 meters (9 to 14 ft) in height with up to 12.2-meter (40 ft) wide openings thus allowing easy access and storage.

Large Volume

Approximately 1,019,520 cubic meters (36,000,000 cubic ft) of salt has been extracted from the Carey mine. In addition, future reserves totalling 50 percent of the previously mined volume is lease held. The estimated waste volume in the WNC region (IV) for the year 1975 is approximately 29,184 cubic meters (1,225,187 cubic ft) or 3.4 percent of the total mined space.

Two Shafts

The Lyons mine was originally a single shaft operation, however, a small access shaft was added for the emplacement of radioactive waste canisters. It is probable that a second main shaft would be needed to meet present federal mine safety standards.

Structurally Stable

The pre-1940 mining area is characterized as having undergone moderate deterioration such as heaving floors, sagging roof, etc. Deterioration is probably correctable by limited remining, clean-up, and stabilization where required. The post-1940 mine area is described as stable and in generally good condition.

Operating

The Lyons mine has been inactive since 1948, but the surface facilities are overseen by a caretaker. The mine was partly reconditioned during the 1960's for the AEC site investigations. It is expected that the mine could be made operable with minimum difficulty.

Accessible to Transportation

The site is convenient to both rail and highway transportation. Large wheeled vehicles have been used as transporters underground.

Nonreactive to Wastes

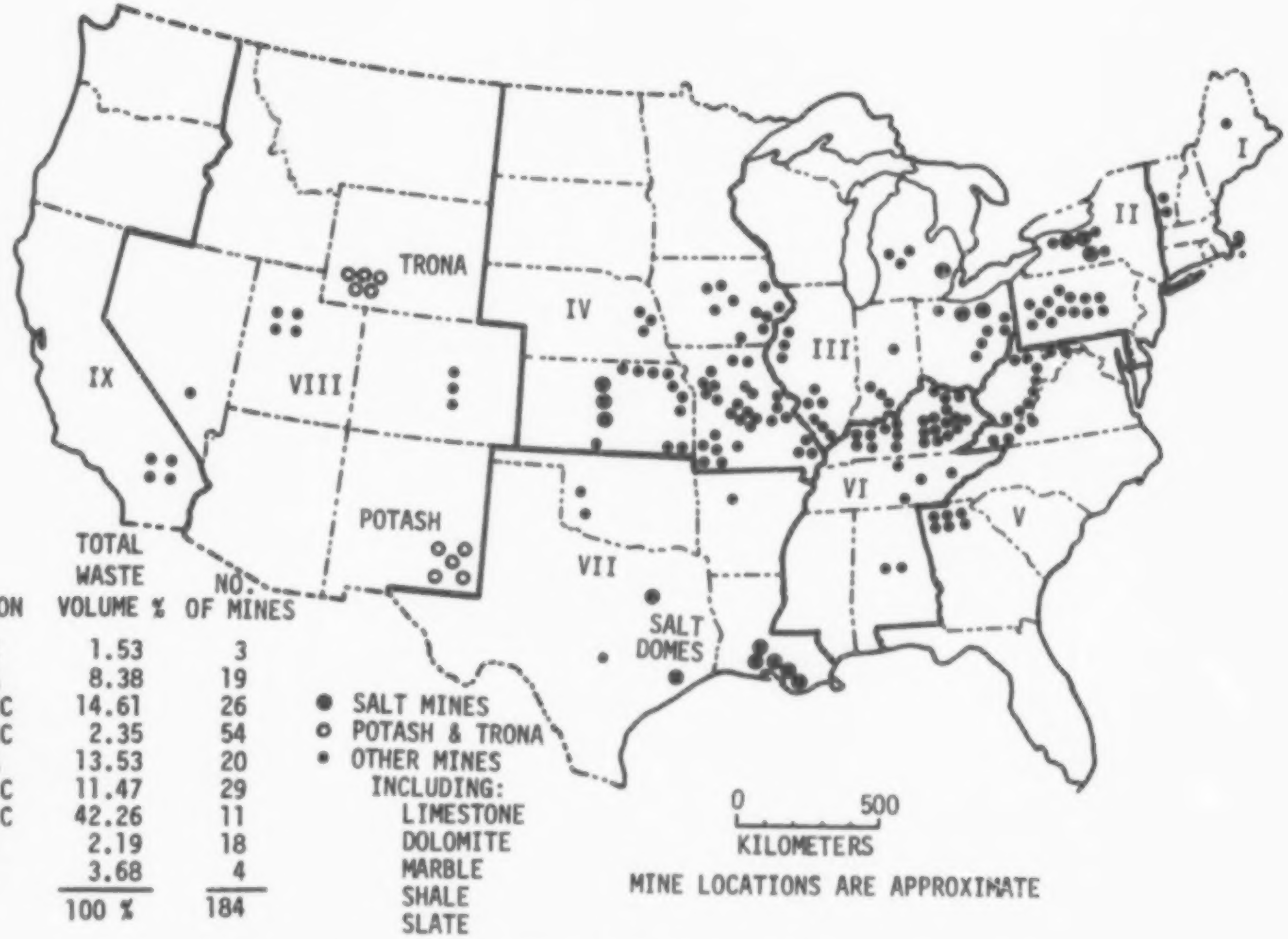
The pure-form compatibility of chemical wastes to salt concluded that none of the geochemical interactions would result in either rapid structural deterioration or increased migration. The containerization requirement makes all interactions of the wastes and host rock highly unlikely.

SUMMARY

A comparison of the inactive Carey salt mine at Lyons, Kansas to the basic technical criteria requisite to safe storage and management of hazardous industrial wastes underground has shown that this mine could be utilized as a safe waste repository. Certain practical and economic considerations would require additional review prior to making a final recommendation; however, all of the purely technical considerations have been met.

The evaluation of the Lyons mine is not intended to be a recommendation of that site, but is made only to indicate the feasibility of the regional waste storage concept using suitable mines.

The regional relationship of potentially suitable underground mines to the volume of hazardous industrial wastes is illustrated in Figure 27. It is clear that every waste region contains at least a few operating mines in the lithologies of interest. Several of these mines can be expected to meet the criteria for hazardous waste storage.


I
II
III
IV
V
VI
VII
VIII
IX
TRONA
POTASH
SALT DOMES
● SALT MINES
○ POTASH & TRONA
• OTHER MINES
INCLUDING:
LIMESTONE
DOLOMITE
MARBLE
SHALE
SLATE
0
500
KILOMETERS
MINE LOCATIONS ARE APPROXIMATE

	REGION	TOTAL WASTE VOLUME %	NO. OF MINES
I	NE	1.53	3
II	MA	8.38	19
III	ENC	14.61	26
IV	WNC	2.35	54
V	SA	13.53	20
VI	ESC	11.47	29
VII	WSC	42.26	11
VIII	M	2.19	18
IX	P	3.68	4
		100 %	184

Figure 27. Regional Relationship of Underground Mines to Waste Volume.

SECTION 11

RECOMMENDATIONS FOR NEEDED RESEARCH

The recommendations for research presented in this section are intended as guidelines in establishing effective programs to enable the storage and management of hazardous waste in underground mines with maximum protection of the environment. This discussion describes the information needed to close existing gaps in technological data and to complete important studies recommended in this report. A general estimate of the funds and time required to complete this research is presented in the Table at the end of this section.

ECONOMICS

As a result of this study, the underground storage of hazardous wastes appears to be technically feasible. It is therefore recommended that a complete economic evaluation of the concept be conducted. Such a study should include the probable cost of:

1. The acquisition of land and the construction and maintenance of surface facilities including docks, warehouses, labs, offices, housing, outbuildings, etc.
2. The acquisition of a mine and the construction and maintenance of underground facilities including shafts, mine rehabilitation, bulkheads, ventilation, etc.
3. The acquisition and maintenance of equipment including forklifts, hoists, hoppers, conveyors, pumps, piping, fans, miscellaneous machinery, electronics, etc.
4. Containers and containerization facilities.
5. Treatment and treatment facilities including chemicals, water, equipment, etc.
6. Miscellaneous items such as commodities, protective clothing and equipment, decontamination facilities, etc.
7. The acquisition, operation, and maintenance of detection, monitoring, and control equipment.
8. Fuel and power requirements.
9. Payroll including labor, inventory, medical, professional, technical, administrative, clerical, security, quality control, etc.

10. Personnel training programs in safety and operation.
11. Annual operation.
12. Future expansion.
13. Public relations and education.

GEOLOGICAL CHARACTERIZATION

To fulfill the contract directive, a listing of existing underground mines in lithologies favorable for waste storage was compiled. This list includes available information as to name, locations, owners, operators, design, and other pertinent data. Following an intensive search of existing literature, it was found that much of the required information was not available for working mines. In addition, such information was almost nonexistent for nonworking mines. Without a comprehensive data base from which to locate mines favorable for waste storage, the further study and evaluation of mines with respect to their suitability as potential sites is severely limited. It is, therefore, recommended that a list of working and nonworking mines be compiled including the following information:

1. Name
2. Location
3. Owner
4. Operator
5. Mining Methods
6. Conditions - number of shafts and levels, depth, age, water conditions, general state of repair, physical dimensions of workings.
7. Geology - description of deposit, dip, visible jointing, faulting, or fracturing.
8. Principal minerals mined and their current and expected economic value or importance.
9. Annual production and extraction ratios.
10. Estimated volume.

Once a study of this general type has been completed, it will be possible to locate favorable potential sites and perform a detailed geological evaluation of their suitability for waste storage. An assessment of each mine is necessary due to the unique nature of each mined opening. Such a study could be conducted in conjunction with the more general study outlined above. It is recommended that the detailed investigation include an analysis of the following:

1. Lithology - composition, strength, chemical properties, alteration, size of deposit.
2. Structure - seismic probability, faults, fractures, joints, stratification, stability.
3. Hydrology - water conditions in mine, location of aquifers in proximity to mine, location of artesian water and other sur-

face water, drainage patterns, rate of salt dissolution.

4. Geomorphology - stability and relief of surface.
5. Complete description of underground workings including dimensions of openings and supports. The location of any abandoned or working drill holes, mines, industry, towns, houses, farms, ranches, etc. in proximity to the site should also be determined.
6. A general evaluation of the environmental suitability for waste storage.

Once the most favorable mines have been indicated geographically and geologically, the final selection of each site should be preceded by an assessment of mine owner and public attitude towards such a facility and an environmental impact statement depicting the potential effects on the environment resulting from the operation of a facility in an area.

The data compiled from these recommended studies would allow the selection of sites having the least probability of future environmental or operational problems.

WASTE CHARACTERIZATION

The purpose of characterizing the wastes was to gain knowledge of their hazards to the environment and to develop methods of reducing those hazards to allow their placement underground while ensuring short and long-term protection of the environment. As stated previously in this study, a pure-form method of analysis was used due to a lack of information on waste streams per se. Since this method of analysis only provides a limited representation of the hazards of actual industrial waste streams, research in this area is recommended. Such a study should include the following:

1. A complete quantitative analysis of all waste streams containing candidate wastes, including the percentage concentration of each constituent and the physical state of the stream as a whole.
2. The detailed analysis of the physical, chemical, and hazardous properties of each waste stream.

In attempting to identify the hazards of waste streams using the pure-form approach, it was found that some pertinent information was lacking. Data concerning the solubilities, densities, boiling points, vapor pressures, flammable or explosive limits in air, volatility, etc. was either conflicting or nonexistent for many of the candidate wastes. Since some industrial waste streams may be suited to a pure-form analysis, or may include compounds requiring treatment in their pure-form, research in these areas is recommended. A form similar to that presented in Appendix B-1 of this study, could be used.

As a task of waste characterization, available data on waste volumes was compiled and estimates of the volumes expected by the years 1975, 1980, and 1985 were made. In attempting to complete this task, it was found that significant amounts of information were lacking. Projection data, in many cases, were found to be too general for application to a specific candidate waste. Much of the information concerning the production and quantification of the wastes was either conflicting or nonexistent. In addition, the pure-form approach complicated matters by prohibiting the use of general waste stream data when the proportionate concentration of a candidate waste was unknown. For these reasons, a detailed study of the volumes of industrial waste streams is recommended. Such a study should include the following information:

1. A breakdown of candidate waste production by industry.
2. The annual volume of each waste candidate generated by each industry.
3. The geographic distribution of the wastes showing areas of concentration.
4. The outlook as to an increase or decrease in waste production.

Since the reduction of the hazards associated with the candidate wastes is essential for the protection of the environment, treatment procedures for the wastes were compiled. These treatment procedures are based upon the pure-form analysis and may not depict all of the products of treatment which may result from an actual waste stream. They do however, represent treatment procedures and products of the most hazardous constituents in waste streams. Within the scope of this study, it was not possible to perform tests of these procedures; hence, they are presented in theory only. It is recommended that a study be conducted to generate the following information:

1. The development of treatment procedures for the candidate wastes whose treatment requires further study (Table 10).
2. An evaluation of the compiled treatment procedures for the candidate waste streams by the application of appropriate chemical engineering principles and tests and amending those needing revision.
3. An application of the tested methods to actual waste streams containing the candidate wastes and amending those needing revision.
4. A detailed analysis of the physical, chemical, and hazardous properties of the treatment of products.
5. The determination of the proper treatment level for storage based on a cost/benefit analysis.

It is the understanding of the investigators that many of these recommended studies are presently being conducted under government contract. However, if the data acquired under these contracts does not provide all the information which has been recommended, the gaps in the technological information will not be fully closed. Since this information is essential to the efficient operation of a waste facility, it is recommended that these studies be expanded where necessary to provide the recommended data.

Since the use of containers is recommended for the underground storage of hazardous wastes, a study should be conducted to determine the proper type of containerization or encapsulation needed to meet the requirements of underground storage. An ideal container would have the following properties:

1. The ability to withstand expected internal and external pressures.
2. The ability to withstand impact loading such as puncture or crushing.
3. Be of a size, weight, and shape which would facilitate fabrication, filling, handling, and storage.
4. Impermeable to liquids or gases.
5. Nonflammable.
6. Chemically inert.
7. Be of a material which would lend itself to mass production.
8. Be permanently labeled.
9. Economical.

GEOCHEMICAL INTERACTION

Within the scope of this study, it was not possible to investigate beyond the first-level chemical interactions of the wastes with each other and geological formations. The obvious potential for further chemical reactions indicates that additional research is needed in this area.

WASTE MIGRATION

Due to the unique physical nature of each mine site, the investigation of the environmental effects of waste migration at each particular site was not possible within the scope of this study. It is recommended that research be done in this area. This research should include an assessment of any physical or biological effects on the environment and any changes in the properties of a waste which may result from waste migration.

DETECTION, MONITORING, AND CONTROL TECHNOLOGY

It is recommended that research be done to develop existing equipment into optimum systems to detect, monitor, and control waste migration. Such systems should be capable of monitoring the air, water, and stability in and around a mined opening to provide ample warning of any impending danger.

LEGISLATION

If the concept is accepted, controlling and safety legislation applicable to the use of underground space for the storage of hazardous wastes will be required.

DEMONSTRATION FACILITY

If an economic study supports the feasibility of the concept, it is recommended that a demonstration facility should be designed, constructed, and operated in order to confirm operating principles and costs. Such a facility would allow a more realistic appraisal of the potential advantages and disadvantages of implementing the concept on a national scale.

ESTIMATE OF TIME AND FUNDS

A generalized estimate of the time and funds which would be required to complete these recommendations is presented in Table 18.

Table 18. RESEARCH ESTIMATE

		Cost Million $	
	Recommended Study	Low	High
1.	Economics	0.070	0.100
2.	Geological assessment		
	A. General mine listing	0.125	0.175
	B. Detailed mine listing	0.060	0.100
	C. Attitude assessment	0.040	0.070
	D. Environmental impact statement	0.100	0.160
3.	Waste characterization		
	A. Properties of waste streams	0.070	0.100
	B. Properties of waste stream constituents	0.200	0.250
	C. Volume study	0.150	0.200
	D. Treatment procedures	0.200	0.250
	E. Containerization/encapsulation	0.250	0.300
4.	Waste/lithology chain reactions	0.050	0.100
5.	Effects of migration	0.300	0.375
6.	Detection, monitoring, and control systems	0.030	0.050
7.	Legislation	0.055	0.095
8.	Demonstration facility-design only	0.500	0.750
9.	Regional concept	0.040	0.060
10.	Nonworking versus working mines	0.040	0.060
	Totals	$2.280	$3.195

Cost estimates based on $60,000/man/yr. of effort.
Between 38.0 and 53.3 man-years are required to complete all recommended studies.

SECTION 12

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SECTION 13

DEFINITIONS

1. Acceptable Waste - Wastes acceptable for underground storage should conform to the following guidelines:
   a. Nonflammable
   b. Nonexplosive
   c. Will not evolve hazardous gases when exposed to air, water, or heat.
   d. Containerized
   e. Unable to be dispersed in air or water in concentrations exceeding the established TLV for the material.

2. Bureau of Census Regions
   a. NE - New England Region including Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
   b. MA - Middle Atlantic Region including New Jersey, New York, and Pennsylvania.
   c. ENC - East North Central Region including Illinois, Indiana, Michigan, Ohio, and Wisconsin.
   d. WNC - West North Central Region including Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.
   e. SA - South Atlantic Region including Delaware, Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia.
   f. ESC - East South Central Region including Alabama, Kentucky, Mississippi, and Tennessee.
   g. WSC - West South Central Region including Arkansas, Louisiana, Oklahoma, and Texas.
   h. M - Mountain Region including Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming.
   i. W - West (Pacific) Region including Alaska, California, Hawaii, Oregon, and Washington.

3. Conventional Mining - Extraction is accomplished by physically or mechanically breaking, loading, and removing the material.

4. Environmental Risk - As used in Appendix B-3, Waste Treatment Procedures, this term refers to a toxic waste treatment product which is essentially nontoxic but should not be disposed of in an uncon-

trolled manner. Such materials are basically nontoxic but might create environmental problems if released freely. Although these products are acceptable for underground storage, their placement underground may not constitute the best use of available mine space if other environmentally acceptable methods are available.

5. Hazard Index (H.I.) - The sum of the ratings of individual hazards indicating a waste's acceptability for underground storage according to the following criteria: H.I. = 0-5, containerization only; H.I. = 6-9, optional treatment; H.I. = 10-25, mandatory treatment.

6. Hazardous Wastes - Waste candidates for underground storage are noxious industrial wastes that present special problems in treatment or handling. Radioactive and wholly military (D.O.D.) wastes are not included.

7. Ideal Mine - The following requirements concerning an ideal mine for the storage of hazardous wastes are based on experience and safety considerations and will be utilized in the screening of favorable mines.
   a. Structurally stable.
   b. Homogeneous deposit.
   c. Dry and impervious.
   d. Nonreactive to waste.
   e. Flat lying floor or horizontal deposit.
   f. Room and pillar mining scheme.
   g. Single level.
   h. Large volume.
   i. Not over 915 meters (3,000 feet) deep.
   j. Accessible to transportation.

8. Mine Environment - The elements that occur in and around a mined opening which would be subject to contamination. These elements include:
   a. The surrounding rock (lithology).
   b. The mine air which takes the form of exhaust.
   c. The ground water surrounding the mined opening either fresh or saline.
   d. Objects not naturally occurring in a mine such as: personnel, equipment, and containers.

9. Modified Mercalli Intensity Scale - An earthquake rating system developed by S.T. Algermissen (NOAA) to indicate relative ground motion based on effects observed on people and objects.

10. Room and Pillar - Mining method whereby large support pillars and level interconnected rooms remain after ore extraction.

11. Recommended Provisional Limit - A concept proposed by TRW Systems Group which was evaluated and subsequently utilized by the investi-

gators in this study. It is a value indicating the concentrations of materials in air or water to which it is believed the environment outside the physical boundaries of processing facilities could be continuously exposed without adverse effects. In air, this value is equal to one-hundredth of the established TLV. In water, the value is equal to the current established drinking water standard or one-hundredth the lowest reported drinking water study level.

12. Threshold Limit Value (TLV) - Values set by the American Conference of Governmental Industrial Hygenists which indicate concentrations of materials in air representing conditions under which it is believed that nearly all workers may be exposed repeatedly for a normal work day over a working lifetime without adverse effect.

13. Treatment Level - Indicates the points at which significant change in the physical form or Hazard Index of a waste occurs during its treatment.

APPENDIX A

OPERATING UNDERGROUND MINES IN SELECTED LITHOLOGIES

OPERATING UNDERGROUND MINES

Salt

Mine Owner	Mine Name	Mine Location
Albert Poulson Salt Co.	Redmund	Utah
American Salt Corp.	American Salt Mine & Mill	Lyons, Kansas
Carey Salt Division of Interpace Corp.	Hutchinson Mine	Hutchinson, Kansas
Cargill, Inc.	Belle Isle Mine	Franklin, Louisiana
Cargill, Inc.	Cayuga Mine & Mill	Myers, New York
Diamond Crystal Salt Co.	Jefferson Island Mine	Jefferson Island, Louisiana
Independent Salt Co.	Kanapolis Mine	Kanapolis, Kansas
International Salt Co.	Cleveland Mine & Mill	Cleveland, Ohio
International Salt Co.	Avery Island Mine	Avery Island, Louisiana
International Salt Co.	Detroit Mine	Detroit, Michigan
International Salt Co.	Retsof Mine	Retsof, New York
Morton Salt Co.	Fairport Mine & Mill	Painsville, Ohio
Morton Salt Co.	Grand Saline Mine & Mill	Grand Saline, Texas
Morton Salt Co.	Seneca Lake Mine & Mill	Penn Yan, New York
Morton Salt Co.	Weeks Island Mine	Weeks Island, Louisiana
Sifto Salt Div. - Domtar Chem. Inc.	Cote Blanche Mine	New Iberia, Louisiana
United Salt Corp.	Hockley Mine & Plant	Hockley, Texas

Potash

Amax Chemical Corp.	Amax Mine	Carlsbad, New Mexico
Duval Corp.	Nash Draw Mine	Carlsbad, New Mexico
Freeport Minerals Co.	Eddy Mine	Carlsbad, New Mexico
Ideal Basic Industries	--	Carlsbad, New Mexico
International Minerals & Chem. Corp.	IMC Mine	Carlsbad, New Mexico
Kerr-McGee Oil Industries, Inc.	Kermac Potash Mine	Carlsbad, New Mexico

Potash

Mine Owner	Mine Name	Mine Location
Potash Company of America	PCA Mine	Carlsbad, New Mexico

Gypsum

Mine Owner	Mine Name	Mine Location
Georgia Pacific Corp.	Blue Rapids Mine & Mill	Blue Rapids, Kansas
Georgia Pacific Corp.	Clarence Center Mine & Akron Mill	Akron, New York
Georgia Pacific Corp.	Kentwood Mine & Mill	Kentwood, Michigan
Georgia Pacific Corp.	Grand Rapids Mine & Mill	Grand Rapids, Michigan
National Gypsum Co.	Clarence Center Mine & Mill	Clarence Center, New York
National Gypsum Co.	Shoals Mine & Mill	Shoals, Indiana
National Gypsum Co.	Shoemaker Mine	Heath, Montana
National Gypsum Co.	Sperry Mine & Mill	Sperry, Iowa
National Gypsum Co.	Sun City Mine & Mill	Sun City, Kansas
United States Gypsum Co.	Locust Cove Mine	Saltville, Virginia
United States Gypsum Co.	Gypsum Mine & Mill	Gypsum, Ohio
United States Gypsum Co.	Oakfield Mine	Oakfield, New York
United States Gypsum Co.	Plaster County No. 6 Mine	Washington, Virginia

Limestone

Mine Owner	Mine Name	Mine Location
Acme Limestone Co.	No. 6 Mine & Mill	Ft. Spring, West Virginia
Acme Limestone Co.	No. 7 Mine	Ft. Spring, West Virginia
Adrian Materials Co.	Adrian Materials Mine & Mill	Jefferson City, Missouri
—	Aggregates Mine & Plant	Elkins, West Virginia
Alabama Limestone Division	Rockwood Mine & Mill	Russellville, Alabama

Limestone

Mine Owner	Mine Name	Mine Location
--	Alrok Mine & Hill	Sugar Creek, Missouri
--	Alton Mine & Hill	Alton, Illinois
--	Arkhola No. 1 Mine	Fort Gibson, Oklahoma
--	Arrowhead Mine & Mill	Brownington, Missouri
--	Ash Grove Mine	Springfield, Missouri
--	Barberton Limestone Mine	Barberton, Ohio
--	Beyer Mine & Mill	Kansas City, Missouri
Black River Mining Co.	Pendleton Underground	Butler, Kentucky
--	Blue Valley No. 2 Mine & Mill	Sugar Creek, Missouri
Boonesboro Quarry Inc.	Boonesboro Quarry	Boonesboro, Kentucky
Bradys Bend Corp.	Bradys Bend Mine & Mill	East Brady, Pennsylvania
--	Bromley Mine & Mill	Atchison, Kansas
Camp Nelson Stone Co.	Camp Nelson Mine	Camp Nelson, Kentucky
--	Carthage Mine & Mill	Carthage, Missouri
Casey Stone Co. Div. Hinkle Contracting Corp.	--	Liberty, Kentucky
--	Catnip Hill Underground	Nicholasville, Kentucky
Cedarstrom Calcite Co.	Cedarstrom Calcite Mine	Lehi, Utah
Central Rock Co., Inc.	Lexington Mine & Mill	Lexington, Kentucky
--	Centropolis Crusher Mine & Mill	Kansas City, Missouri
--	Chester Quarry & Mill	Chester, Illinois
--	Clay County Mine & Mill	W. Excelsior Springs, Missouri
--	Clinton Mine & Mill	Clinton, Missouri
Columbia Rock Products Corp.	Columbia Mine & Mill	Columbia, Tennessee
--	Columbus Junction Mine & Mill	Columbus Junction, Iowa
Cowan Stone Company	Anderson Mine	Sherwood, Tennessee

Limestone

Mine Owner	Mine Name	Mine Location
--	Crestmore Mine	Riverside, California
Diamond Springs Lime Co.	Diamond Springs Mine	Diamond Springs, California
--	Douds Mine & Mill	Douds, Iowa
--	Durham Mine No. 152	Harvey, Iowa
El Dorado Limestone Co., Inc.	El Dorado Mine	Shingle Spring, California
--	Federal Mine	Cape Girardeau, Missouri
--	Fort Dodge Mine & Mill	Fort Dodge, Iowa
Fort Hartford Stone Co., Inc.	Hartford Mine	Olaton, Kentucky
Franklin Limestone Co.	Crab Orchard Mine & Mill	Crab Orchard, Tennessee
Geoghegan & Mathis, Inc.	Lockport Mine & Mill	Lockport, Kentucky
--	Glanns Creek Underground Mine	Frankfort, Kentucky
Greer Steel Co.	Greer Limestone Mine	Greer, West Virginia
--	Griesemer Mine & Mill	Springfield, Missouri
Hinkle Contracting Co.	Tipton Ridge Mine	Ravenna, Kentucky
--	Holland Mine & Mill No. 1	Lenexa, Kansas
--	Holland Mine No. 2	Lenexa, Kansas
Great Western Sugar Co.	Horse Creek Mine	Denver Co., Wyoming
--	Jonathan Mine & Mill	East Fultunham, Ohio
--	K. C. Quarries Mine & Mill	Kansas City, Missouri
--	Kelly Mine & Mill	Newark, Missouri
Kentucky Stone Co.	Mt. Vernon Mine & Mill	Mt. Vernon, Kentucky
"	Mullins Mine & Mill	Mt. Vernon, Kentucky
"	Tyrone Mine & Mill	Lawrenceburg, Kentucky
"	Yellow Rock Mine & Mill	Yellow Rock, Kentucky
--	Lapel Mine	Lapel, Indiana
--	Lees Summit Mine & Mill	Kansas City, Missouri

Limestone

Mine Owner	Mine Name	Mine Location
--	Liberty Mine & Mill	Liberty, Missouri
--	Linwood Mine & Mill	Buffalo, Iowa
Liters Quarry, Inc.	Crestwood Mine & Mill	Crestwood, Kentucky
M. A. Walker Co., Inc.	Clover Bottom Mine	McKee, Kentucky
"	Indian Creek Mine	McKee, Kentucky
M&M Lime Co.	Mine & Plant	Worthington, Pennsylvania
--	Malcom Mine & Mill	Malcolm, Iowa
Manheim Quarry Co.	Manheim Mine	Morgantown, West Virginia
--	Marengo Mine & Mill	Marengo, Indiana
--	Marion Plant	Marion, Kentucky
Marquette Cement Mfg., Co.	Deckers Creek Mine	Deckers Creek, West Virginia
--	Michel Mine	Marble Falls, Texas
--	Midland Quarry Mine & Mill	S. Atchison, Kansas
--	Mine No. 1	Quincy, Illinois
--	Mine & Mill No. 2	Quincy, Illinois
--	Mine No. 3 & Mill	South Quincy, Illinois
--	Moberly Mine & Mill	Webster City, Iowa
--	Monahan Mine	Lenexa, Kansas
National Gypsum Co.	Belfonte #3	Belfonte, Pennsylvania
"	Kimballton Quarry & Mill	Kimballton, Virginia
Nevada Test Site	--	Mercury, Nevada
--	North Cave Mine & Mill	Carthage, Missouri
--	Northwest Quarry Mine & Mill	Warsaw, Missouri
--	Osage Asphalt Mine & Mill	Osage Beach, Missouri
--	Peerless Mine & Mill	St. Genevieve, Missouri
Penn Dixie Cement Corp.	West Winfield #9 Plant	West Winfield, Pennsylvania

Limestone

Mine Owner	Mine Name	Mine Location
--	Pine Hill Mine & Mill	Blue Springs, Missouri
--	Pixley Mine & Mill	Independence, Missouri
--	Pleasant Gap Mine & Mill	Pleasant Gap, Pennsylvania
Porter Construction Co.	Rogers Mine & Mill	Rogers, Kentucky
--	Prairie Du Rocher Quarry & Mill	Prairie Du Rocher, Illinois
--	Princeton Mine & Mill	Princeton, Kentucky
--	Quincy Quarry & Mill	Quincy, Illinois
--	Ragland Mine & Mill	Leitchfield, Kentucky
Ralph Rogers & Co., Inc.	Pilot Knob Mine & Mill	Gallatin, Tennessee
--	Randolph Mine & Mill	Randolph, Missouri
Riverside Stone Co.	Riverside Mine & Mill	Battletown, Kentucky
--	Rock Acres Mine & Mill	Independence, Missouri
--	Ronen Mine & Mill	Stone City, Iowa
American Cyanide Co.	Sargent Calcium Products Mine	Weeping Water, Nebraska
--	South Mine & Mill	Texas, Maryland
Southern Cement Co.	Roberta Mine & Mill	Calera, Alabama
Southwest Lime Co.	Mine & Mill	Neosho, Missouri
St. Clair Lime Co.	No. 2 Mine & Mill	Marble City, Oklahoma
--	Stotz Quarry & Mill	Prairie Du Rocher, Illinois
--	Sugar Creek Underground Garage and Storage	Sugar Creek, Missouri
--	Thomasville Stone & Lime Co.	Thomasville, Pennsylvania
--	Tobin Mine & Mill	Kansas City, Kansas
--	Underground Mine & Mill	Kansas City, Kansas
--	United Mineral Mine & Mill	Weeping Water, Nebraska
--	Valmeyer No. 3 Quarry & Mill	Valmever, Illinois

Limestone

Mine Owner	Mine Name	Mine Location
--	Van Lerberg Mine	Lenexa, Kansas
Vetter Bros. Inc.	Dry Quarry & Mill	Deep Creek, Maryland
Sub-Range Air Corp.	Virginia Lime Co. Mine	Ripplemead, Virginia
Vulcan Materials Co.	Richmond Road Mine & Mill	Lexington, Kentucky
Warner Co.	Bellefonte Plant & Mine	Bellefonte, Pennsylvania
Winfield Lime & Stone Co., Inc.	Winfield Mine	W. Winfield, Pennsylvania
--	Young American Mine & Mill	Washington, Iowa

Marble

--	Felch Quarry & Mill	Felch, Michigan
Georgia Marble Co.	Cove Mountain Mine & No. 6 Mill	Whitestone, Georgia
"	Fassett Mine & No. 7 Mill	Whitestone, Georgia
Marble Products Of Georgia	No. 5 Mine	Whitestone, Georgia
--	New York Mine	Tate, Georgia
--	No. 1 Mine	Whitestone, Georgia
--	Rush Tower Mine & Mill	Festus, Missouri
Vermont Marble Co.	Danby-Imperial Quarry	Proctor, Vermont
"	Main No. 2 Quarry	W. Rutland, Vermont
--	Weiler Marble Mine	Bloomdale, Missouri
--	Whitestone No. 1 Mine	Whitestone, Georgia

Clay, Shale (Includes Slate)

--	Chamblin No. 2	Crow Junction, Colorado
Colonial Clay Products Co.	Clay Mine	Bridgeville, Pennsylvania
Continental Clay Products Co.	Clay Mine	Kittanning, Pennsylvania

Clay, Shale (Includes Slate)

Mine Owner	Mine Name	Mine Location
Crescent Brick Co., Inc.	Hardins Run	New Cumberland, W. Virginia
--	Dando Mine & Plant	Irondale, Ohio
--	Dragon No. 2	Eureka, Utah
--	Drexel Refractries	Kittanning, Pennsylvania
Freeport Brick Co.	Clay Mine	Freeport, Pennsylvania
Glove Refractories, Inc.	Glove No. 1 Mine & Plant	Newell, West Virginia
Hanley Company	Hanley No. 4A Mine & Mill	Bradford, Pennsylvania
--	Hogback No. 1 & 2	Waterton, Colorado
--	Irondale Works Mine & Mill	Irondale, Ohio
--	Kokoneef Caverns	Mountain Pass, California
--	No. 5 Mine	Monson, Maine
--	Port Washington Mine & Mill	Port Washington, Ohio
--	Rock Creek Mine	-- , Colorado
Stone Creek Brick Co.	Mine & Mill	Stone Creek, Ohio

APPENDIX B

WASTE CHARACTERIZATION

APPENDIX B-1

HAZARDOUS WASTE PROPERTIES

Note: Toxicology statements were obtained in the literature when available. Others were postulated using the best available information and experience.

Name: Acrolein **ID no:** 8

Formula: CH_2:CHCHO **H.I.:** 22

Solubility: H_2O(cold): 21 g/100cc H_2O(hot): 24 g/100cc

Density: 0.841 g/cc @ 20°C **Vapor pressure:** 215mm Hg@ 20°C
TRW
@ 678.5mm Hg@ 50°C
@ @

Flammability hazard: Severe. Vapor is extremely flammable. Flash point < 18°C. Ignition temperature 278°C.

Explosive hazard: Severe. Vapor is explosive. Explosive limits in air (wt.%) 2.8 (lower) to 31 (upper).

Volatile hazard: Severe. Evolves acrolein vapors in ambient air. Boils @ 52.5°C.

Toxicology: Extremely toxic by ingestion, inhalation, or absorption through skin in both liquid and vapor forms. It affects particularly membranes of the eyes and respiratory tract.

TLV: **In air:** 0.1 mg/m³

Provisional limit: **In air:** mg/m³ **In water:** 0.01 mg/l

Special precautions: Treatment at point of origin recommended, due to transport hazard.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Aldrin **ID no:** 13

Formula: $C_{12}H_8Cl_6$ **H.I.:** 9

Solubility: H$_2$O(cold): 2×10^{-6} g/100cc H$_2$O(hot): NA g/100cc

Density: 1.650 g/cc @ **Vapor pressure:** 6×10^{-6} mm @ 25°C

@ @

@ @

Flammability hazard: Slight. May be flammable depending on solvent used in formulation. May emit flammable gases when heated to decomposition.

Explosive hazard: Slight. May emit explosive gases when heated to decomposition.

Volatile hazard: None at ambient temperature. Evolves toxic fumes of Cl_2 and HCl when heated to decomposition. May emit gaseous hydrocarbons and hydrogen when heated to decomposition. Melts at 104°C.

Toxicology: Highly toxic by ingestion, inhalation, absorption through skin. Cumulative in liver. Causes irritability, convulsions and depression in from 1 to 4 hours.

TLV: **In air:** 0.25 mg/m^3

Provisional limit: **In air:** .0025 mg/m^3 **In water:** 0.012 mg/l

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Ammonium Chromate **ID no:** 21

Formula: $(NH_4)_2CrO_4$ **H.I.:** 18

Solubility: H_2O(cold): 40.5 g/100cc H_2O(hot): Decomposes g/100cc

Density: 1.91 g/cc @ 12°C **Vapor pressure:** NA @

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@ @

Flammability hazard: Severe. Highly flammable and also a very strong oxidant. Will ignite spontaneously if contaminated with an oxidizable material (wood, paper, or other organic material).

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Evolves NH_3 on contact with air or heat.

Toxicology: Highly toxic by ingestion, inhalation, or absorption through skin. Chromate salts have been associated with cancer of the lungs. May cause ulcerous lesions or perforation of nasal sceptum.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** 0.001 mg/m^3 as CrO_3 **In water:** 0.05 mg/l as Cr

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation.

Comments: Weakly basic in H_2O. Not acceptable for underground storage without treatment. Treatment products compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Ammonium Dichromate **ID no:** 22

Formula: $(NH_4)_2Cr_2O_7$ **H.I.:** 18

Solubility: H_2O(cold): 30.8 g/100cc @ 15°C H_2O(hot): 89 g/100cc @ 30°C

Density: 2.15 g/cc @ 25°C **Vapor pressure:** NA @

@ @

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Flammability hazard: Severe. Highly flammable, decomposition becomes self sustaining at 225°C. Strong oxidant and will ignite spontaneously if contaminated with an oxidizable material.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Evolves NH_3 on contact with air or heat.

Toxicology: Highly toxic by ingestion, inhalation, or absorption through skin. Inhalation can cause asthmatic symptoms. Ingestion may lead to kidney injury and ulceration of the stomach.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** 0.001 mg/m^3 **In water:** 0.05 mg/l as Cr

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation.

Comments: Weak acid in H_2O. Not acceptable for underground storage without treatment. Treatment products compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Ammonium Picrate **ID no:** 27

Formula: $NH_4C_6H_2N_3O_7$ **H.I.:** 21

Solubility: H_2O(cold): 1 g/100cc H_2O(hot): Decomposes g/100cc

Density: 1.72 g/cc @ **Vapor pressure:** NA @

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Flammability hazard: Severe. Highly flammable. May detonate when subjected to a flame.

Explosive hazard: Severe. Autoignition temperature 423°C. Explodes.

Volatile hazard: None at ambient conditions. Evolves NO_x when burned.

Toxicology: Moderately toxic by ingestion and inhalation. Discolors skin and may cause dermatitis.

TLV: In air: 0.01 mg/m^3 (recommended)

Provisional limit: In air: 0.001 mg/m^3 as picric acid In water: 0.005 mg/l

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation.

Comments: When heated, it emits toxic fumes of oxides of nitrogen. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Antimony Pentafluoride **ID no:** 36

Formula: SbF_5 **H.I.:** 11

Solubility: **H_2O(cold):** Infinite g/100cc **H_2O(hot):** Infinite g/100cc

Density:	3.145 g/cc	@ 15.5°C	**Vapor pressure:**	4.3mm Hg	@	25°C
	2.99 g/cc	@ 23°C		18mm Hg	@	50°C
		@		170mm Hg	@	100°C

Flammability hazard: Nonflammable but do not use water to control fires when SbF_5 is present, as fumes will be given off and heat evolved.

Explosive hazard: Nonexplosive but highly reactive with water and other materials. Contamination of SbF_5 with other materials could cause explosion.

Volatile hazard: Severe. Moderate to high volatility at ambient temperatures. Boils @ 149.5°C. Evolves toxic gases (SbF_5 and possibly HF) when contacted by H_2O. Highly reactive with many materials. Fumes in air and evolves HF. Will evolve toxic gases with heat.

Toxicology: Highly toxic by ingestion, inhalation, or absorption through skin in both liquid and vapor forms. May damage lungs, heart, and liver.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.05 (Sb) mg/l

Special precautions: Keep dry and covered. Absorbs water from air. Protective clothing and respirators required in handling.

Comments: Strongly acid in H_2O. Very corrosive when wet. Not acceptable for underground storage without treatment. Treatment products compatible with rock salt, gypsum, potash, shale (1), shale (2) limestone and granite lithology.

Name: Antimony Trifluoride ID no: 43

Formula: SbF_3 H.I.: 11

Solubility: H_2O(cold): 385 g/100cc @0°C H_2O(hot): 564 g/100cc

Density:	4.379 g/cc @ 20.9°C	Vapor pressure:	3mm Hg	@ 17°C
	@		107mm Hg	@ 62°C
	@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive, but highly reactive with water and other materials. Contamination with other materials could cause an explosion.

Volatile hazard: Severe. Moderate to high volatility at ambient temperatures. Melts @ 292°C. Boils @ 376°C. Sublimes @ 319°C. Evolves toxic SbF_3 and possibly HF on contact with air, water, or heat.

Toxicology: Highly toxic by ingestion, inhalation, or absorption through skin in both liquid and vapor forms. May damage lungs, heart, and liver.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 mg/m^3 In water: 0.05 Sb mg/l

Special precautions: Keep dry and covered. Will absorb water from air. Protective clothing and respirators required in handling.

Comments: Acid in H_2O. Becomes very corrosive when wet. Not acceptable for underground storage without treatment. Treatment products compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Arsenic Trichloride **ID no:** 50

Formula: $AsCl_3$ **H.I.:** 11

Solubility: H_2O(cold): Decomposes g/100cc H_2O(hot): Decomposes g/100cc

Density: (Liquid) 2.163 @ 14°/4°C **Vapor pressure:** 10mm Hg @ 23.5°C

(Vapor) 6.25 @ NA @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Highly volatile. Decomposes to HCl (liquid or gas) and As_2O_3 on contact with water. BP 130.2°C. Fumes on contact with air or heat.

Toxicology: Highly toxic by ingestion, inhalation, or absorption through skin. May be fatal.

TLV: **In air:** 0.5 as As mg/m^3

Provisional limit: **In air:** 0.005 as As mg/m^3 **In water:** 0.05 as As mg/l

Special precautions: Protective clothing, including approved respirator. Avoid exposing to air.

Comments: Strong acid in H_2O. Corrosive with water. Not acceptable for underground storage without treatment. Treatment products compatible with rock salt, gypsum, potash and limestone lithology.

Name: Arsenic Trioxide ID no: 51

Formula: As_2O_3 H.I.: 7

Solubility: H_2O(cold): 3.7 g/100cc H_2O(hot): 10.1 g/100cc

Density:	3.865 g/cc	@	25°C (Arsenolite)	Vapor pressure:		@	
	4.15 g/cc	@	25°C (Claudetite)			@	
	4.09 g/cc	@	25°C (Amorphous)		760mm Hg	@	193°C

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: None at ambient conditions. Severe hazard if exposed to heat. Evolves toxic vapors at 193°C. Boils at 457.2°C.

Toxicology: Highly toxic by ingestion and inhalation. Skin contact can cause dermatitis. Ingestion of 0.1 grams is fatal.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 mg/m^3 as As In water: 0.05 mg/l as As

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation. Avoid contact with heat.

Comments: Weak acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum and potash lithology.

Name: Benzene Hexachloride (Lindane) ID no: 55

Formula: $C_6H_6Cl_6$ H.I.: 8

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	1.85	@	Vapor pressure:	9.4×10^{-6} mm	@ 20°C
		@			@
		@			@

Flammability hazard: Slight. May emit flammable gases when heated to decomposition.

Explosive hazard: Slight. Products of decomposition may include gaseous hydrocarbons and H_2 which could explode in the presence of air.

Volatile hazard: None at ambient conditions. Melts @ 112.9°C. Severe hazard when heated to decomposition (see comments).

Toxicology: Moderately toxic by ingestion, inhalation, and absorption through skin. Vapors irritate eyes, nose and throat. May have cumulative effects.

TLV:	In air:	0.5	mg/m^3			
Provisional limit:	In air:	0.005	mg/m^3	In water:	0.025	mg/1

Special precautions: Protective clothing, including approved respirator to avoid dust inhalation. Avoid heating.

Comments: Melting point 112.9°C. Decomposition products include highly toxic chlorine, hydrogen chloride and phosgene. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Boron Hydride (Decaborane) ID no: 61,505

Formula: $B_{10}H_{14}$ H.I.: 25

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): Dissociates g/100cc

Density:	0.94 g/cc	@ 20°C	Vapor pressure:	19mm Hg	@	100°C
		@		66mm Hg	@	132°C
		@			@	

Flammability hazard: Extreme. Flash point 80°C. Autoignition temperature 149°C.

Explosive hazard: Extreme. Highly reactive with oxidizing materials, water, or steam, rubbers, greases, halogenated hydrocarbons.

Volatile hazard: Extreme. Highly reactive with water to evolve flammable and explosive hydrogen gas. Evolves hazardous fumes with heat.

Toxicology: Extremely toxic by ingestion and inhalation. Can cause dizziness, visual disturbance, injury to liver and kidneys.

TLV:	In air:	0.05 mg/m³			
Provisional limit:	In air:	0.0005 mg/m³	In water:	0.015	mg/l

Special precautions: $B_{10}H_{14}$ is more stable than the other boron hydrides listed. However, the same precautions should be taken.

Comments: TLV data is questionable. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Boron Hydride (Diborane) **ID no:** 61,505

Formula: B_2H_6 **H.I.:** 25

Solubility: H_2O(cold): Dissociates g/100cc H_2O(hot): Dissociates g/100cc

Density: 0.577 g/cc @ -183°C **Vapor pressure:** 22 mm @ -112°C

@ @

@ @

Flammability hazard: Extreme. Autoignition temperature 40°C - 50°C. Flammability limits in air from $> 0.9\%$ (lower) to $> 98\%$ (upper). Flash point -90°C.

Explosive hazard: Extreme. Explosive limits in air from $< 0.9\%$ (lower) to $> 98\%$ (upper). Highly reactive with water or steam to produce H_2. Reacts explosively with oxidizing materials, rubber, greases, halogenated hydrocarbons.

Volatile hazard: Extreme. Boils at -9.25°C.

Toxicology: Extremely toxic by inhalation and ingestion. Emergency exposure limit 10 ppm for 10 minutes, 5 ppm for 30 minutes, 2 ppm for 60 minutes. Can cause dizziness, injury to liver and kidneys.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 In water: 0.005 mg/l

Special precautions: Avoid contamination. Small quantities of impurity renders Diborane extremely unstable.

Comments: Contact with water will release explosive hydrogen. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Boron Hydride (Hexaborane) **ID no:** 61,505

Formula: B_6H_{10} **H.I.:** 25

Solubility: **H_2O(cold):** Hydrolyzes g/100cc **H_2O(hot):** Disassociates g/100cc

Density: @ **Vapor pressure:** 7.2mm Hg @ 0°C

Liquid 0.69 @ 0°C @

Gas 2.6 @ 0°C @

Flammability hazard: Extreme.

Explosive hazard: Extreme.

Volatile hazard: Extreme. Highly reactive with water to evolve flammable and explosive hydrogen gas.

Toxicology: Extremely toxic by inhalation and ingestion. Can cause dizziness, injury to liver and kidneys.

TLV: **In air:** NA mg/m^3

Provisional limit: **In air:** NA mg/m^3 **In water:** NA mg/l

Special precautions: Avoid contaminants. B_6H_{10} reacts explosively with a wide range of materials, including moisture.

Comments: Contact with water will release explosive hydrogen. Not recommended for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Bromine Pentafluoride **ID no:** 66

Formula: BrF_5 **H.I.:** 25

Solubility: H_2O(cold): Explodes g/100cc H_2O(hot): Explodes g/100cc

Density: 2.57 g/cc	@ 0°C	**Vapor pressure:** 100mm Hg	@ -4.5°C
2.47 g/cc	@ 25°C	400mm Hg	@ 25.7°C
	@	362mm Hg	@ 22°C

Flammability hazard: Extreme. Will ignite oxidizible materials on contact.

Explosive hazard: Extreme. Reacts explosively with water.

Volatile hazard: Extreme. See vapor pressure data above. Boils @ 40.5°C.

Toxicology: Extremely toxic by inhalation, ingestion, and absorption through skin. Severe burns, attacks eyes. 50 ppm can be fatal in 30 minutes.

TLV: In air: 0.7 mg/m^3

Provisional limit: In air: 0.007 mg/m^3 In water: Explodes mg/l

Special precautions: Disposal at point of origin recommended, due to transport hazard. Highly reactive with every known element except oxygen, nitrogen, and inert gases.

Comments: Decomposition products on reaction w/water are highly acid. Not acceptable for underground storage in any form. Treatment products are hazardous. Recommend recycling.

Name: Cacodylic Acid **ID no:** 80

Formula: $(CH_3)_2AsOOH$ **H.I.:** 9

Solubility: H_2O(cold): Very soluble g/100cc H_2O(hot): Very soluble g/100cc

Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
		@			@

Flammability hazard: Slight. May evolve flammable gases when heated to decomposition.

Explosive hazard: Slight. May evolve explosive gases when heated to decomposition.

Volatile hazard: None at ambient conditions. Severe hazard if heated to decomposition. Decomposition may include gaseous hydrocarbons or hydrogen gas.

Toxicology: Highly toxic by ingestion, moderately toxic by inhalation (dust or spray). Affects stomach, intestines, liver, blood and kidneys.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 mg/m^3 as As In water: 0.05 mg/l as As

Special precautions: Approved respirator. Avoid heating.

Comments: Acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, and potash lithology.

Name: Cadmium (solid) ID no: 81

Formula: Cd H.I.: 3

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	8.642 g/cc	@	Vapor pressure:	1mm	@ 394°C
		@		10mm	@ 484°C
		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile @ ambient temperatures.

Toxicology: As a solid, toxic by ingestion only. Cd dust is toxic, see separate rating sheet.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/1

Special precautions: Approved respirator, gloves, protective clothing.

Comments: Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Cadmium (Powdered) **ID no:** 82

Formula: Cd **H.I.:** 18

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	@	**Vapor pressure:**	1mm	@ 394°C
	@		10mm	@ 484°C
	@			@

Flammability hazard: Severe. Highly flammable if dispersed in air. Moderately flammable when exposed to oxidizing agents.

Explosive hazard: Severe. Dangerously explosive when dispersed in air. Moderately explosive when exposed to oxidizing agents.

Volatile hazard: Nonvolatile @ ambient temperatures.

Toxicology: Toxic by inhalation and ingestion. Breathing of dust may be fatal. May be inhaled without immediate symptoms.

TLV: **In air:** 0.2 mg/m^3

Provisional limit: **In air:** 0.002 mg/m^3 **In water:** 0.01 mg/l

Special precautions: Approved respirator, clothing.

Comments: Not recommended for underground storage without treatment. The treatment product is compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Cadmium Chloride **ID no:** 83

Formula: $CdCl_2$ **H.I.:** 5

Solubility:	H_2O(cold):	140 g/100cc @ 20°C	H_2O(hot):	150 g/100cc @ 100°C	
Density:	4.047 g/cc @ 25°C		**Vapor pressure:**	10mm	@ 656°C
	@			40mm	@ 736°C
	@				@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. Causes sudden nausea. May be fatal.

TLV: **In air:** 0.2 mg/m^3

Provisional limit: **In air:** 0.002 mg/m^3 **In water:** 0.01 mg/l

Special precautions: Approved respirator, gloves, protective clothing.

Comments: Strongly acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), and granite lithology.

Name: Cadmium Cyanide ID no: 84

Formula: $Cd(CN)_2$ H.I.: 24

Solubility: H_2O(cold): 1.7 g/100cc @ 15°C H_2O(hot): Soluble g/100cc

Density: 2.226 @ 20 Vapor pressure: NA @

Decomposes @ > 200°C @

@ @

Flammability hazard: Severe. Evolves highly flammable HCN on contact with air, acids, acid fumes, heat, or moisture.

Explosive hazard: Severe. Evolves explosive HCN on contact with air, acids, acid fumes, heat, or moisture.

Volatile hazard: Severe. Evolves HCN on contact with air, acids, acid fumes, heat or moisture. HCN is a toxic, flammable, and explosive gas.

Toxicology: Toxic by ingestion, inhalation, or absorption through skin. May be fatal. Affects respitory tract and kidneys.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/l

Special precautions: Protective clothing and approved respirator.

Comments: Weak acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Cadmium Fluoride **ID no:** 478

Formula: CdF_2 **H.I.:** 5

Solubility: H_2O(cold): 4.35 g/100cc H_2O(hot): NA g/100cc

Density: 6.64 g/cc @ Vapor pressure: 1mm Hg @ 1112°C

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion, inhalation, and absorption. Causes sudden nausea. May be fatal.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 as Cd mg/m^3 In water: 0.01 as Cd mg/l

Special precautions: Approved respirator, protective clothing.

Comments: Acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, and potash lithology.

Name: Cadmium Nitrate ID no: 479

Formula: $Cd(NO_3)_2$ H.I.: 17

Solubility: H_2O(cold): 109 g/100cc H_2O(hot): 326 g/100cc

Density: @ Vapor pressure: NA @

@ @

@ MP 350°C @

Flammability hazard: An oxidizing material may react with easily oxidizable substances to cause ignition or explosion.

Explosive hazard: May react with easily oxidizable substances to cause explosion.

Volatile hazard: Nonvolatile. At ambient conditions. Melts @ 350°C. May evolve toxic fumes with heat.

Toxicology: Toxic by ingestion inhalation and absorption through skin. Causes sudden nausea. May be fatal.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/l

Special precautions: Avoid contact with oxidizible materials or reducing agents as fire or explosion may result.

Comments: Acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Cadmium Oxide **ID no:** 85

Formula: CdO **H.I.:** 2

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	6.95 (Amorphous)	@	**Vapor pressure:**	1mm	@	1000°C
	8.15 (Crystalline)	@			@	
		@			@	

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. Causes sudden nausea. May be fatal.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** .001 mg/m^3 **In water:** 0.01 mg/l

Special precautions: Avoid inhalation of dust.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Cadmium Phosphate (Ortho) **ID no:** 86

Formula: $Cd_3(PO_4)_2$ **H.I.:** 2

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. Causes sudden nausea. May be fatal.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/1

Special precautions: Approved respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Cadmium Potassium Cyanide **ID no:** 480

Formula: $Cd(CN)_2 \cdot 2KCN$ **H.I.:** 24

Solubility: **H_2O(cold):** 33.3 g/100cc **H_2O(hot):** 100 g/100cc

Density: 1.847 @ 15°C **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. Evolves flammable HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Severe. Evolves HCN gas on contact with air, moisture, heat, acids, or acid fumes. HCN gas is toxic, flammable, and explosive.

Toxicology: Toxic by ingestion, inhalation, or absorption through skin. Causes sudden nausea. May be fatal.

TLV: **In air:** 0.2 mg/m^3

Provisional limit: **In air:** 0.002 mg/m^3 **In water:** 0.01 mg/l

Special precautions: Protective clothing and approved respirator.

Comments: Base in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Cadmium Sulfate **ID no:** 481

Formula: $CdSO_4$ **H.I.:** 5

Solubility: **H_2O(cold):** 75.5 g/100cc **H_2O(hot):** 60.8 g/100cc

Density: 4.69 g/cc @ 20°C/4°C **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. Causes sudden nausea. May be fatal.

TLV: **In air:** 0.2 mg/m^3

Provisional limit: **In air:** 0.002 mg/m^3 **In water:** 0.01 mg/l

Special precautions: Approved respirator.

Comments: Acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, and granite lithology.

Name: Calcium Arsenate (Ortho) **ID no:** 87

Formula: $Ca_3(AsO_4)_2$ **H.I.:** 3

Solubility: **H_2O(cold):** 0.013 g/100cc @ 25°C **H_2O(hot):** NA g/100cc

Density: 3.620 g/cc @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. Poisonous in small amounts.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 as As **In water:** 0.05 mg/l as As

Special precautions: Approved respirator.

Comments: Slightly basic in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Calcium Arsenite **ID no:** 88

Formula: $CaAsO_3H$ **H.I.:** 4

Solubility: **H_2O(cold):** NA g/100cc **H_2O(hot):** NA g/100cc

Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile, but emits toxic fumes of arsenic when heated to decomposition or on contact with acids or acid fumes.

Toxicology: Toxic by ingestion or inhalation. May be fatal.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.05 as As mg/1

Special precautions: Approved respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Calcium Cyanide **ID no:** 91

Formula: $Ca(CN)_2$ **H.I.:** 24

Solubility:	H_2O(cold): Decomposes g/100cc		H_2O(hot): Decomposes g/100cc		
Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
	Decomposes	@ > 350°C			@

Flammability hazard: Severe. Evolves flammable hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Severe. Liberates toxic, flammable, and explosive hydrocyanic acid gas on contact with air, moisture, heat, acids, or acid fumes. May liberate acetylene on contact with moisture.

Toxicology: Highly toxic by ingestion and inhalation of dust. Products of decomposition extremely toxic by inhalation. May be fatal.

TLV:	**In air:**	5 mg/m^3			
Provisional limit:	**In air:**	0.05 mg/m^3	**In water:**	0.01 as CN	mg/l

Special precautions: Approved respirator.

Comments: Weak base in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Chlordane **ID no:** 484

Formula: $C_{10}H_6Cl_8$ **H.I.:** 12

Solubility: **H_2O(cold):** Insoluble g/100cc **H_2O(hot):** Insoluble g/100cc

Density: 1.57-1.67 @ 15°C **Vapor pressure:** 1×10^{-5} @ 25°C

@ @

BP 175°C

@ @

Flammability hazard: Slight. May emit flammable gases when heated to decomposition. Also may be flammable depending upon solvent used in formulation.

Explosive hazard: Slight. May emit explosive gases when heated to decomposition.

Volatile hazard: Severe. Liberates toxic and corrosive HCL on contact with water. When heated to decomposition emits HCL and may evolve gaseous hydrocarbons or H_2 which will burn or explode.

Toxicology: Toxic by ingestion, inhalation, and absorption through skin. May cause liver damage.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.025 mg/l

Special precautions: Protective clothing and respirator. Keep dry.

Comments: Corrosive when wet. Not recommended for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Chlorine ID no: 105

Formula: Cl_2 H.I.: 21

Solubility: H_2O(cold): 0.8 @ 10°C g/100cc H_2O(hot): 0.54 @ 30°C g/100cc

Density:	1.468	@	0°C (liquid)	Vapor pressure:	85 psi	@	21°C
	3.214 g/l	@	0°C (Gas)		151.12 psi	@	40°C
		@			174.69 psi	@	46°C

Flammability hazard: Moderate. Can react to cause fires with turpentine, ether, ammonia gas, illuminating gas, hydrocarbons, hydrogen, and powdered metals.

Explosive hazard: Moderate. Can react to cause explosions (see above).

Volatile hazard: Extreme. A gas at ambient temperatures. Emits highly toxic fumes when heated. Will react with water or steam to form toxic and corrosive HCL.

Toxicology: Toxic by inhalation, ingestion, or absorption through skin. Irritates mucous membrane of the eyes and respiratory tract. May be fatal.

TLV: In air: 3 mg/m^3

Provisional limit: In air: 0.03 mg/m^3 In water: 0.15 mg/l

Special precautions: Protective clothing, goggles, approved respirator.

Comments: Acid in water. Corrosive. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Chlorine Pentafluoride **ID no:** 106

Formula: ClF_5 **H.I.:** 25

Solubility: **H_2O(cold):** Decomposes g/100cc **H_2O(hot):** Decomposes g/100cc

Density: 1.75 g/cc @ 20°C **Vapor pressure:** 2.44psia @ -50°C

@ 8.85 psia @ -25°C

@ 58.76 psia @ 25°C

Flammability hazard: Extreme. Ignites spontaneously.

Explosive hazard: Extreme. Reacts violently w/oxidizable materials, metals, etc. Also reacts violently with small quantities of water, and smoothly with larger quantities.

Volatile hazard: Extreme. See vapor pressure data above. Liberates volatile Cl_2 and HF with large quantities of water. Boils @ -13.1°C.

Toxicology: Extremely toxic by inhalation, ingestion, and absorption through skin. Decomposes w/water to toxic Cl_2 + HF. May be fatal.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** 0.001 mg/m^3 **In water:** 0.0.02 as HF mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: This is the provisional limit of the most toxic of the decomposition products formed by the reaction of CF_5 with water. Decomposition products highly acid. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Chlorine Trifluoride **ID no:** 106

Formula: ClF_3 **H.I.:** 25

Solubility:	H_2O(cold):	Decomposes g/100cc		H_2O(hot):	Decomposes g/100cc
Density:	1.77	@ 13°C	**Vapor pressure:**	504mm Hg	@ 2.37°C
		@		185mm Hg	@ -17°C
		@			@

Flammability hazard: Extreme. Ignites spontaneously.

Explosive hazard: Extreme. Reacts violently w/oxidizable materials, metals, etc.

Volatile hazard: Extreme. Boils at 11.8°C.

Toxicology: Extremely toxic by ingestion, inhalation, and absorption through skin. May be fatal.

TLV:	**In air:**	0.1 mg/m^3			
Provisional limit:	**In air:**	0.001 mg/m^3	**In water:**	0.01 as HF	mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Decomposition products on reaction w/water are highly acid. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Chromic Acid **ID no:** 114

Formula: CrO_3 **H.I.:** 15

Solubility: H_2O(cold): 164.9 g/100cc 0°C **H_2O(hot):** 206.9 g/100cc @ 100°C

Density: 2.70 @ 20°C **Vapor pressure:** NA @
@ @
@ @

Flammability hazard: Moderate. A strong oxidant, and capable of igniting other materials.

Explosive hazard: Moderate. Could cause explosion by contacting powerful reducing agents.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by inhalation, ingestion, and absorption through skin. Irritates skin and mucous membrane.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** 0.001 mg/m^3 as CrO_3 **In water:** 0.05 mg/l as Cr_2O_3

Special precautions: Protective clothing and respirator.

Comments: Acid in H_2O. Corrosive. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Copper Acetoarsenite (Paris Green) **ID no:** 490

Formula: $(CH_3CO_2)_2Cu\cdot 3Cu(AsO_2)_2$ **H.I.:** 9

Solubility: **H_2O(cold):** NA g/100cc **H_2O(hot):** NA g/100cc

Density: NA @ **Vapor pressure:** NA @
@ @
@ @

Flammability hazard: Slight. May evolve flammable gases on heating to decomposition.

Explosive hazard: Slight. May evolve explosive gases when heated to decomposition.

Volatile hazard: Severe. Evolves toxic fumes of arsenic when heated to decomposition.

Toxicology: Toxic by inhalation and ingestion. May be fatal.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.05 mg/1

Special precautions: Approved respirator, protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), and granite lithology.

Name: Copper Acetylide ID no: 517

Formula: Cu_2C_2 H.I.: 19

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	NA	@	Vapor pressure:	NA	@
		@			@
		@			@

Flammability hazard: Severe. Extremely heat sensitive.

Explosive hazard: Severe. Explosively sensitive to heat, spark, flame, impact, or friction.

Volatile hazard: Severe. Evolves toxic gases upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Moderately toxic by inhalation and ingestion.

TLV: In air: NA mg/m^3

Provisional limit: In air: 0.01 mg/m^3 In water: 1.0 as Cu mg/l

Special precautions: High explosive. Handle with caution.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Copper Arsenate **ID no:** 119

Formula: $Cu_3(AsO_4)_2 \cdot 4H_2O$ **H.I.:** 2

Solubility: H_2O(cold):	Insoluble g/100cc		H_2O(hot):	Insoluble	g/100cc
Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion and inhalation. May be fatal in small amounts.

TLV:	In air:	0.5	mg/m^3			
Provisional limit:	In air:	0.005 as Cu	mg/m^3	In water:	0.05 as Cu	mg/l

Special precautions: Approved respirator, protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Copper Chlorotetrazole* **ID no:** 518

Formula: Not available. **H.I.:** 20

Solubility:	H_2O(cold):	NA	g/100cc	H_2O(hot):	NA	g/100cc
Density:	NA	@		**Vapor pressure:**	NA	@
		@				@
		@				@

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Highly sensitive to heat, impact, electrical discharge, and friction. A sensitive primary explosive.

Volatile hazard: Nonvolatile at ambient conditions. Severe hazard if explosively decomposed. Evolves toxic gases.

Toxicology: Probably slightly toxic by ingestion or inhalation.

TLV:	**In air:**	1.0 as Cu	mg/m^3			
Provisional limit:	**In air:**	0.01 as Cu	mg/m^3	**In water:**	1.0 As Cu	mg/1

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: *U.S. Government classified information. Physical data not available. Not acceptable for underground storage without additional information. Treatment products are probably compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Copper Cyanide (Cupric Cyanide) **ID no:** 120

Formula: $Cu(CN)_2$ **H.I.:** 22

Solubility:	**H_2O(cold):**	Insoluble g/100cc	**H_2O(hot):**	NA	g/100cc
Density:	NA @		**Vapor pressure:**	NA @	
	@			@	
Decomposes before M.P.	@			@	

Flammability hazard: Severe. Evolves flammable HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Severe. Evolves HCN (hydrocyanic acid) gas on contact with air, moisture, heat, acids, or acid fumes. HCN gas is flammable, explosive, and toxic. $Cu(CN)_2$ decomposes at ambient temperatures evolving HCN and other hazardous gases.

Toxicology: Evolves toxic HCN gas on decomposition. Toxic by ingestion, inhalation. Moderately toxic by absorption through skin. May be fatal.

TLV:	**In air:**	1.0 as Cu	mg/m^3			
Provisional limit:	**In air:**	0.01 as Cu	mg/m^3	**In water:**	0.01 as CN	mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Weak acid. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Copper Cyanide (Cuprous Cyanide) **ID no:** 128

Formula: CuCN **H.I.:** 22

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: 2.92 g/cc @ **Vapor pressure:** @

@ @

@ @

Flammability hazard: Severe. Evolves highly flammable HCN gas on contact with air, heat, moisture, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive HCN gas on contact with air, heat, moisture, acids, or acid fumes.

Volatile hazard: Severe. Evolves HCN gas on contact with air, heat, moisture, acids, or acid fumes. HCN gas is flammable, explosive, and toxic.

Toxicology: Toxic by ingestion, inhalation. Moderately toxic by absorption through skin.

TLV:	**In air:**	1.0 as Cu	mg/m^3			
Provisional limit:	**In air:**	0.01 as Cu	mg/m^3	**In water:**	0.01 as CN	mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Note: Provisional limit in air reported as Cu. Provisional limit in water reported as CN. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Cyanides **ID no:** 129

Formula: Varies **H.I.:** 24

Solubility: H_2O(cold): Varies g/100cc H_2O(hot): Varies g/100cc

Density: Varies @ **Vapor pressure:** Varies @

@ @

@ @

Flammability hazard: Severe. Will evolve flammable HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Will evolve explosive HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Will evolve HCN gas on contact with air, heat, moisture, acids, or acid fumes. HCN gas is flammable, explosive and toxic.

Toxicology: Vapors highly toxic by ingestion and inhalation. Moderately toxic by absorption through skin. May be fatal.

TLV: **In air:** 5 mg/m^3

Provisional limit: **In air:** 0.05 as CN mg/m^3 **In water:** 0.01 as CN mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: DDD **ID no:** 136

Formula: $(ClC_6H_4)_2HCCHCl_2$ **H.I.:** 9

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

MP 110°C @ @

Flammability hazard: Slight. Products of decomposition may be flammable.

Explosive hazard: Slight. Products of decomposition may explode in presence of air.

Volatile hazard: Severe. Heating to decomposition may evolve highly toxic chloride fumes and H_2. Nonvolatile at ambient conditions.

Toxicology: Moderately toxic by inhalation, ingestion and absorption through skin. Evolves highly toxic chloride fumes when heated to decomposition.

TLV: In air: 1.0 mg/m^3

Provisional limit: In air: 0.01 mg/m^3 In water: 0.05 mg/l

Special precautions: Avoid heating. Protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: DDT ID no: 137

Formula: $(ClC_6H_4)_2CHCCl_3$ H.I.: 9

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): NA g/100cc

Density: NA @ Vapor pressure: $1.5\text{x}10^{-7}$ mm Hg @ 20°C

@ @

MP 109°C @ @

Flammability hazard: Slight. Products of decomposition may be flammable.

Explosive hazard: Slight. Products of decomposition may explode in presence of air.

Volatile hazard: Severe. Melts @ 109°C. Decomposition temperature 110°C, above which volatile and toxic gases will be evolved. May evolve H_2 upon decomposition. Nonvolatile at ambient conditions.

Toxicology: Moderately toxic by ingestion, inhalation, and absorption through skin.

TLV: In air: 1 mg/m^3

Provisional limit: In air: 0.01 mg/m^3 In water: 0.05 mg/l

Special precautions: Avoid heating. Protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Demeton **ID no:** 491

Formula: $C_8H_{19}O_3S_2P$ **H.I.:** 9

Solubility:	H_2O(cold): Insoluble	g/100cc	H_2O(hot):	Insoluble	g/100cc
Density:	1.13 g/cc	@	Vapor pressure:	0.001 mm Hg	@ 33°C
		@			@
		@			@

Flammability hazard: Slight. May evolve flammable gases when heated to decomposition.

Explosive hazard: Slight. May evolve explosive gases when heated to decomposition.

Volatile hazard: Severe. Evolves toxic gases when heated to decomposition. Boils @ 134°C. Nonvolatile at ambient conditions.

Toxicology: Extremely toxic by ingestion, inhalation, and absorption through skin. May cause headache, blurred vision, nausea. Ingestion is immediately fatal.

TLV:	In air:	0.1 mg/m^3			
Provisional limit:	In air:	0.001 mg/m^3	In water:	0.005	mg/l

Special precautions: Avoid heating. Protective clothing, respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Detonators and Primers **ID no:** 520

Formula: Varies **H.I.:** 17

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. Extremely heat sensitive.

Explosive hazard: Severe. Explosively sensitive to heat, flame, spark, impact, or friction.

Volatile hazard: Severe. Explosive decomposition may emit toxic gases. Nonvolatile at ambient conditions.

Toxicology: Not known.

TLV: In air: NA mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended, due to transport hazard.

Comments: Physical data not applicable for this general classification. Not acceptable for underground storage without treatment. Treatment products are compatible with gypsum, shale (1), shale (2), limestone and granite lithology.

Name: Diazodinitrophenol (DDNP) **ID no:** 521

Formula: $C_6H_2(NO_2)_2ON{=}N$ **H.I.:** 20

Solubility: H_2O(cold): Almost Insoluble g/100cc H_2O(hot): NA g/100cc

Density: 1.63 g/cc @ **Vapor pressure:** Low @

@ @

@ @

Flammability hazard: Severe. Extremely heat sensitive.

Explosive hazard: Severe. Explosively sensitive to heat, spark, flame, friction, mechanical or electrical shock.

Volatile hazard: Severe. Explosive decomposition may emit toxic gases. Nonvolatile at ambient conditions.

Toxicology: Not known. Probably toxic by ingestion and possibly by absorption through skin.

TLV: **In air:** Not Established mg/m^3

Provisional limit: **In air:** NA mg/m^3 **In water:** NA mg/l

Special precautions: High explosive. Handle with caution. Treatment at point of origin recommended.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Dichlorophenoxyacetic Acid (2, 4-D) ID no: 135

Formula: $C_8H_6Cl_2O_3$ H.I.: 8

Solubility: H_2O(cold): 0.06 g/100cc H_2O(hot): NA g/100cc

Density: NA @ Vapor pressure: 0.4mm @ 160°C

@ @

MP 138-140°C @ @

Flammability hazard: Slight. May evolve flammable gases when heated to decomposition.

Explosive hazard: Slight. May evolve explosive gases when heated to decomposition.

Volatile hazard: Severe. When heated to decomposition may evolve gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Moderate toxicity. When heated to decomposition, highly toxic fumes of hydrogen chloride and other chlorinated products are emitted. Can cause nausea and vomiting. Noncumulative.

TLV: In air: 10 mg/m^3

Provisional limit: In air: 0.1 mg/m^3 In water: 0.5 mg/l

Special precautions: Avoid heating.

Comments: Acid in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, and potash lithology.

Name: Dieldrin **ID no:** 149

Formula: $C_{12}H_8OCl_6$ **H.I.:** 9

Solubility: H_2O(cold): 0.05 g/100cc H_2O(hot): NA g/100cc

Density: 1.75 g/cc @ **Vapor pressure:** 1.8×10^{-7} mm Hg @ 20°C

@ @

MP 175-176°C @ @

Flammability hazard: Slight, depending on solvent used in formulation. Products of decomposition may be flammable.

Explosive hazard: Slight. May emit explosive gases when heated to decomposition.

Volatile hazard: Severe. Melts @ 176°C. Products of decomposition may include gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion, inhalation, and absorption through skin. Emits toxic fumes when heated to decomposition. May cause nausea, and dizziness.

TLV: In air: 0.25 mg/m^3

Provisional limit: In air: 0.0025 mg/m^3 In water: 0.012 mg/l

Special precautions: Avoid heating. Protective clothing, respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Dimethyl Sulfate **ID no:** 160

Formula: $(CH_3)_2SO_4$ **H.I.:** 20

Solubility: H$_2$O(cold): 2.8 g/100cc H$_2$O(hot): NA g/100cc

Density: 1.3283 @ 20°C **Vapor pressure:** 15mm @ 76°C

@ @

BP 188.5°C @ @

Flammability hazard: Moderate. Will burn at temperatures above flash point (115.6°C open cup).

Explosive hazard: Moderate. May react explosively with bases and oxidizers.

Volatile hazard: Severe at ambient and higher temperatures.

Toxicology: Extreme by ingestion, inhalation, and absorption through skin. May cause liver and kidney damage. Irritates mucous membrane. May be fatal. Insidious poison due to latent appearance of symptoms and lack of odor.

TLV: In air: 5 mg/m^3

Provisional limit: In air: 0.05 mg/m^3 In water: 0.25 mg/1

Special precautions: Respirator and protective clothing. Avoid heating.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Dinitrocresol (DNOC) **ID no:** 162

Formula: $(NO_2)_2C_6H_2(CH_3)OH$ **H.I.:** 13

Solubility: H_2O(cold): 0.013 g/100cc H_2O(hot): NA g/100cc

Density:	@	Vapor pressure: $5.2\text{x}10^{-5}$ mm	@ 25°C
	@		@
MP 86.4°C	@		@

Flammability hazard: Moderate. Strong oxidizer. May ignite oxidizible materials.

Explosive hazard: Moderate. Forms highly soluble salts on reaction with caustic alkalies, ammonia, and organic amines. These salts, when dry, are explosive.

Volatile hazard: Slight. May emit toxic fumes when heated to decomposition. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion, inhalation and absorption through skin. May damage liver and kidneys. Cumulative poison.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/l

Special precautions: Respirator and protective clothing.

Comments: Readily forms water-soluble basic salts. Acts as a weak acid. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Dinitrotoluene **ID no:** 165

Formula: $(NO_2)_2C_6H_3CH_3$ **H.I.:** 21

Solubility: H_2O(cold): 0.2 g/100cc H_2O(hot): NA g/100cc

Density: 1.321 g/cc @ 71°C **Vapor pressure:** NA @

1.521 g/cc @ 20°C @

MP 69.5°C BP 300°C @ @

Flammability hazard: Severe. Highly reactive with reducing substances.

Explosive hazard: Severe. Subject to detonation. Sensitive to heat or flame.

Volatile hazard: Severe. Evolves toxic nitrous oxides upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion, inhalation, and to a lesser extent, by skin contact. May cause anemia and liver damage.

TLV: In air: 1.5 mg/m^3

Provisional limit: In air: 0.015 mg/m^3 In water: 0.075 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Not recommended for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Dipentaerythritol Hexanitrate (DPEHN) **ID no:** 522

Formula: $C_{10}H_{16}N_6O_{19}$ **H.I.:** 20

Solubility: H_2O(cold): Nearly Insoluble g/100cc H_2O(hot): NA g/100cc

Density: 1.63 @ 23°C **Vapor pressure:** NA @

@ @

MP 73.7°C @ @

Flammability hazard: Severe. Extremely sensitive to heat.

Explosive hazard: Severe. Sensitive to heat, impact, and friction. Explodes when heated to 255°C.

Volatile hazard: Severe. Evolves toxic nitrous oxides upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Moderately toxic by ingestion and inhalation of dust.

TLV: **In air:** 2 Estimated mg/m^3

Provisional limit: **In air:** 0.02 mg/m^3 **In water:** 0.1 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Endrin ID no: 170

Formula: $C_{12}H_8Cl_6O$ H.I.: 9

Solubility: H_2O(cold): 0.19 g/100cc H_2O(hot): NA g/100cc

Density:	NA @		Vapor pressure:	2×10^{-7} mm @ 25°C
	@			@
	@			@

Flammability hazard: Slight. May emit flammable gases when heated to decomposition. May have a flammable solvent incorporated in formulation.

Explosive hazard: Slight. May emit explosive gases when heated to decomposition.

Volatile hazard: Severe. Emits toxic fumes of chlorides when heated to decomposition. Decomposition temperature 200°C. Decomposition products may include gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion, inhalation, and absorption through skin. Residual in system. Causes headache, nausea, dizziness, attacks central nervous system.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 In water: 0.005 mg/l

Special precautions: Avoid heating. Protective clothing and respirator.

Comments: Emits toxic fumes when heated to decomposition. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Fluorine **ID no:** 200

Formula: F_2 **H.I.:** 19

Solubility: H_2O(cold): Reacts g/100cc H_2O(hot): Reacts g/100cc

Density: 1.507 g/cc @ -188°C **Vapor pressure:** 19.7 psia@ -185°C

@ 164.7 psia@ -156°C

@ 794.7 psia@ -129°C

Flammability hazard: Moderate to severe. Oxidizes nearly all materials. Will spontaneously initiate combustion with some inflammable materials.

Explosive hazard: Slight. May react explosively with other materials.

Volatile hazard: Extreme. A toxic gas at ambient temperatures.

Toxicology: Extremely toxic by inhalation, ingestion, and absorption through skin. Very irritating to skin, eyes, and throat.

TLV: **In air:** 0.1 mg/m^3

Provisional limit: **In air:** 0.001 mg/m^3 **In water:** Reacts

Special precautions: Protective clothing and respirator.

Comments: Reaction products w/H_2O highly acid. Not acceptable for underground storage without treatment.

Name: GB (Nonpersistent Nerve Gas) ID no: 287

Formula: $(CH_3)_3COHPOF$ H.I.: 10

Solubility: H_2O(cold): Miscible g/100cc H_2O(hot): Miscible g/100cc

Density:	@	Vapor pressure:	1.48mm	@ 20°C
(Liquid) 1.0887 g/cc	@ 25°C		8mm	@ 46°C
(Gas) 4.86 (Air=1)	@ NA		12mm	@ 50°C

MP -56°C BP 147°C

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Moderate. Fumes slightly in ambient air. Severe hazard when heated due to liberation of toxic fumes.

Toxicology: Extremely toxic by inhalation, ingestion, and absorption through skin. May be fatal in small amounts. Used as war gas.

* TLV: In air: 0.000003 mg/m^3

Provisional limit: In air: 0.00000003 mg/m^3 In water: NA mg/l

Special precautions: Respirator and protective clothing. Avoid heating.

Comments: *Maximum concentration U.S. Army recommendation. Not a listed TLV. Not acceptable for underground storage without treatment.

Name: Gelatinized Nitrocellulose ID no: 523

Formula: Varies from $C_{12}H_{17}(ONO_2)_3O_7$ to $C_{12}H_{14}(ONO_2)_6O_4$ H.I.: 18

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	1.5 g/cc	@	Vapor pressure:	NA	@
		@			@
		@			@

Flammability hazard: Severe. Autoignition temperature 160°C.

Explosive hazard: Severe.

Volatile hazard: Severe. Emits toxic nitrous oxides upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Only slightly toxic, however, solvents used in formulation may be toxic.

TLV: In air: NA mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended, due to transport hazard.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Glycol Dinitrate (DDN) ID no: 525

Formula: $C_2H_4(ONO_2)_2$ H.I.: 23

Solubility: H_2O(cold): 0.68 g/100cc H_2O(hot): 0.92 g/100cc

Density: 1.489 g/cc @ 20°C Vapor pressure: 0.05 mm @ 20°C

@ 1.4 mm @ 60°C

@ 5.9 mm @ 80°C

Flammability hazard: Severe. Very sensitive to heat. Highly reactive with reducing substances.

Explosive hazard: Severe. Powerful explosive sensitive to slight impact, heat, flame, sparic, or friction. Explosive decomposition evolves high heat and shock wave.

Volatile hazard: Slight hazard in ambient air. Severe hazard when heated. Explosive decomposition evolves toxic fumes of nitrous oxides.

Toxicology: Highly toxic by inhalation, ingestion, and absorption through skin.

TLV: In air: 2 mg/m^3

Estimated

Provisional limit: In air: 0.02 mg/m^3 In water: 0.1 mg/l

Estimated

Special precautions: Treatment at point of origin recommended due to transport hazard. Rexpirator and protective clothing. High explosive.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Gold Fulminate **ID no:** 526

Formula: $Au(CNO)_2$ (?) **H.I.:** 20

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. Highly sensitive to heat.

Explosive hazard: Severe. Detonates when exposed to mild thermal, mechanical, or electrical shock.

Volatile hazard: Severe. Evolves toxic gases upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Not known. Assumed toxic.

TLV: In air: NA mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Not acceptable for underground storage. Further study is needed for treatment procedure. *Information is classified.

Name: Guthion ID no: 495

Formula: $C_{10}H_{12}N_3O_3PS_2$ H.I.: 9

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): Slight g/100cc

Density:	1.44 g/cc	@	Vapor pressure:	NA	@
		@			@
		@			@

Flammability hazard: Slight. May emit flammable gases when heated to decomposition.

Explosive hazard: Slight. May emit explosive gases when heated to decomposition.

Volatile hazard: Severe. On heating to decomposition, emits toxic vapors of HCL. Melts @ 96°C. Decomposition products may include gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion, inhalation of dust and absorption through skin. Emits highly toxic fumes of NO_x, phosphorus and sulfur compound when heated to decomposition. Ingestion is instantly fatal.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/l

Special precautions: Avoid heating. Protective clothing and respirators.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Heptachlor **ID no:** 496

Formula: $C_{10}H_5Cl_7$ **H.I.:** 9

Solubility: H_2O(cold): Practically Insoluble g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** 3×10^{-4} mm @ 25°C

@ @

MP 95-96°C @ @

Flammability hazard: Slight. On heating to decomposition may emit flammable vapors. May exhibit flammable properties depending upon solvent used in formulation.

Explosive hazard: Slight. On heating to decomposition may emit explosive vapors.

Volatile hazard: Severe. On heating to decomposition, emits toxic vapors of HCL. Melts @ 96°C. Decomposition products may include gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion, inhalation of dust, and absorption through skin. 1 to 3 grams ingested or absorbed are fatal.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.025 mg/l

Special precautions: Avoid heating. Protective clothing and respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Hydrogen Sulfide **ID no:** 221

Formula: H_2S **H.I.:** 24

Solubility: H_2O(cold): 430 g/100cc H_2O(hot): 186 g/100cc

Density: .0015 g/cc @ Ambient **Vapor pressure:** 300 psia @ 24°C

@ 80 psia @ -18°C

MP -85.5°C @ 400 psia @ 38°C

Flammability hazard: Severe. Autoignition temperature 260°C.

Explosive hazard: Severe. Explodes on ignition in concentrations of from 4.3 to 46% H_2S in air.

Volatile hazard: Severe. A toxic, flammable, and explosive gas at ambient conditions. Emits highly toxic oxides of sulphur when heated to decomposition.

Toxicology: Highly toxic by inhalation, even in very low concentration in air. High concentrations immediately fatal. Paralyzes respiratory tract. Rotten egg odor. Skin irritant.

TLV: In air: 15 mg/m^3

Provisional limit: In air: 0.15 mg/m^3 In water: 0.75 mg/l

Special precautions: Do not use in conjunction with copper or brass tubing or fittings. Respirator and protective clothing.

Comments: Acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Lead Arsenate **ID no:** 235

Formula: $PbHAsO_4$ **H.I.:** 4

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Slightly soluble g/100cc

Density: 5.79 g/cc @ **Vapor pressure:** NA @

@ @

MP 720°C. @ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Slight. Emits toxic fumes when heated to decomposition.

Toxicology: Highly toxic by ingestion and inhalation of dust. Emits toxic fumes when heated. May be fatal. Lead is a cumulative poison. Skin irritant.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 mg/m^3 as As In water: 0.05 mg/l as As

Special precautions: Avoid heating. Respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Lead Arsenite **ID no:** 236

Formula: $Pb(AsO_2)_2$ **H.I.:** 3

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: 5.85 g/cc @ **Vapor pressure:** @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Slight. Emits toxic fumes when heated to decomposition.

Toxicology: Toxic by ingestion and inhalation of dust. Emits toxic fumes on heating. May be fatal. Lead is a cumulative poison.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 mg/m^3 as As In water: 0.05 mg/1 as As

Special precautions: Avoid heating. Respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Lead Azide **ID no:** 529

Formula: $Pb(N_3)_2$ **H.I.:** 21

Solubility: H_2O(cold): 0.02 g/100cc H_2O(hot): 0.09 g/100cc

Density: 4.38 g/cc @ 25°C **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. Reactive with copper, zinc, and sodium hydroxide.

Explosive hazard: Severe. Detonates when exposed to very mild thermal, mechanical, or electrical shock. Hard to ignite by direct flame. Subject to spontaneous explosion during crystallization.

Volatile hazard: Severe. Emits toxic gases upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion and inhalation. Moderately toxic by absorption through skin. Lead is a cumulative poison. May be fatal.

TLV: **In air:** 0.15 mg/m^3

Provisional limit: **In air:** 0.0015 mg/m^3 as Pb **In water:** 0.05 mg/l as Pb

Special precautions: Treatment at point of origin recommended, due to transport hazard.

Comments: Explodes at 350°C. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Lead Cyanide ID no: 239

Formula: $Pb(CN)_2$ H.I.: 23

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): Soluble g/100cc

Density:	NA	@	Vapor pressure:	NA	@
		@			@
		@			@

Flammability hazard: Severe. Evolves flammable HCN.

Explosive hazard: Severe. Evolves explosive HCN.

Volatile hazard: Severe. Evolves HCN gas on contact with air, moisture, heat, acids, or acid fumes. HCN gas is toxic, flammable, and explosive.

Toxicology: Highly toxic by ingestion. $Pb(CN)_2$ in solution will evolve HCN gas if solution is only mildly acid (i.e. on contact w/CO_2 in air). Moderately toxic by absorption through skin. May be fatal.

TLV: In air: 0.15 mg/m^3

Provisional limit: In air: 0.0015 as Pb mg/m^3 In water: 0.05 as Pb mg/l

Special precautions: Avoid contact with air, moisture, heat, acids, or acid fumes. Respirator.

Comments: Weak acid. Not acceptable for storage without treatment. Treatment products of PbO + NaCl are compatible with gypsum, limestone and granite lithology. Treatment products of PbO + $CaCl_2$ are compatible with gypsum, shale (1), shale (2), limestone and granite lithology.

Name: Lead 2, 4 Dinitroresorcinate (LDNR) **ID no:** 530

Formula: $C_6H_2O_6N_2Pb$ **H.I.:** 19

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	3.2 g/cc @	**Vapor pressure:**	Very Low @
	@		@
	@		@

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Undergoes detonation when subjected to very mild mechanical or electrical shock.

Volatile hazard: Severe. Evolves toxic fumes upon explosive decomposition.

Toxicology: Toxic by ingestion and inhalation of dust (lead poisoning). Moderately toxic by absorption through skin. Lead is a cumulative poison. May be fatal.

TLV: In air: 0.15 mg/m^3

Provisional limit: In air: 0.0015 as Pb mg/m^3 In water: 0.05 as Pb mg/l

Special precautions: Treatment at point of origin recommended due to transport hazards.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible with gypsum, shale (1), shale (2), limestone and granite lithology.

Name: Lead Styphnate **ID no:** 531

Formula: $C_6H(NO_2)_3(O_2Pb)$ **H.I.:** 20

Solubility:	H_2O(cold):	Insoluble	g/100cc	H_2O(hot):	NA	g/100cc
Density:	3.00	@ 20°C		**Vapor pressure:**	NA	@
		@				@
		@				@

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Undergoes detonation when subjected to very mild mechanical, electrical, or thermal shock.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion and inhalation of dust. Moderately toxic by absorption through skin. Lead is a cumulative poison. May be fatal. Attacks central nervous system.

TLV:	In air:	0.15	mg/m^3			
Provisional limit:	In air:	0.0015 as Pb	mg/m^3	In water:	0.05 as Pb	mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive detonating agent.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible with gypsum, shale (1), shale (2), limestone and granite lithology.

Name: Lewisite **ID no:** 243

Formula: $C_2H_2AsCl_3$ **H.I.:** 11

Solubility: H_2O(cold): 0.05 g/100cc H_2O(hot): NA g/100cc

Density: @ **Vapor pressure:** 0.4mmHg @ 25°C(Trans)

(Liquid) 1.86 g/cc @ 25°C 1.56^2mmHg @ 25°C(cis)

BP 196.6°C(Trans) 169.8°C(cis) @ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Fumes in air. When heated to decomposition evolves toxic fumes of HCl and arsenic. Tends to decompose on long term storage. Evolves toxic gases on contact with water.

Toxicology: Highly toxic by ingestion, inhalation, and absorption through skin. Will blister the skin. Fatal in small amounts. Attacks mucous membranes and eyes. Will penetrate leather, wood, rubber, and cloth. Used as war gas.

TLV: In air: NA mg/m^3

Provisional limit: In air: $3x10^{-6}$ mg/m^3 Estimated In water: $1.5x10^{-5}$ mg/l Estimated

Special precautions: Penetrates some protective clothing. Respirator.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Magnesium Arsenite **ID no:** 245

Formula: $Mg_3(AsO_3)_2$ **H.I.:** 4

*The physical/chemical properties of Magnesium Arsenite are not given because Magnesium Arsenite is not a compound but a name applied to a group of compounds.

Solubility: **H_2O(cold):** Slight g/100cc **H_2O(hot):** Slight g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Toxic by ingestion, inhalation, and absorption through skin. Not as toxic as other Arsenic Compounds.

TLV:	**In air:**	0.5 as As	mg/m^3			
Provisional limit:	**In air:**	0.005 as As	mg/m^3	**In water:**	0.05 as As	mg/l

Special precautions: Respirator, protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), and granite lithology.

Name: Manganese Arsenate ID no: 500

Formula: $MnHAsO_4$ H.I.: 3

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): NA g/100cc

Density: NA @ Vapor pressure: NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion, inhalation, and absorption through skin. May be fatal.

TLV: In air: 0.5 mg/m^3

Provisional limit: In air: 0.005 as As mg/m^3 In water: 0.05 as As mg/1

Special precautions: Respirator, protective clothing.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Mannitol Hexanitrate ID no: 532

Formula: $C_6H_8(NO_3)_6$ H.I.: 18

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): NA g/100cc

Density:	1.603	@ 0°C	Vapor pressure:	Low	@
		@			@
		@			@

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Detonates when subjected to a very mild electrical, mechanical, or thermal shock.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion. May cause weakness, headache, and dizziness.

TLV: In air: 2 mg/m^3

Provisional limit: In air: 0.02 mg/m^3 Estimated In water: 0.1 mg/l Estimated

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Explodes at 120°C. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Mercuric Chloride **ID no:** 253

Formula: H_gCl_2 **H.I.:** 10

Solubility: **H_2O(cold):** 6.9 g/100cc **H_2O(hot):** 48 g/100cc

Density: 5.440 g/cc@ 25°C **Vapor pressure:** 1 mm @ 136.2°C

@ 10 mm @ 180.2°C

MP 276°C BP 302°C @ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Evolves toxic fumes w/heat. See vapor pressure data. Slight hazard at ambient conditions.

Toxicology: Highly toxic by ingestion, inhalation of dust or fumes. Absorption through skin is slow. May be fatal.

TLV: **In air:** 0.05 as Hg mg/m^3

Provisional limit: **In air:** 0.0005 as Hg mg/m^3 **In water:** 0.005 as Hg mg/l

Special precautions: Avoid heating. Approved respirator.

Comments: Acid in H_2O. Not acceptable for underground storage. Recommend recycling.

Name: Mercuric Cyanide ID no: 254

Formula: $Hg(CN)_2$ H.I.: 25

Solubility: H_2O(cold): 9.3 g/100cc H_2O(hot): 53 g/100cc

Density: 4.00 g.cc @ 20°C Vapor pressure: NA @

@ @

@ @

Decomposition Temperature 320°C.

Flammability hazard: Severe. Evolves flammable hydrocyanic acid gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. May form explosive mercuric oxycyanide when reacted with mercuric oxide or mercuric chloride. Evolves explosive HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Severe. Evolves hydrocyanic acid gas on contact with air, moisture, heat, acids, or acid fumes. HCN is toxic, flammable, and explosive. Evolves toxic fumes of mercury when heated to decomposition.

Toxicology: Highly toxic by ingestion, inhalation of dust or fumes, and absorption through skin. May be fatal.

TLV:	In air:	0.05 as Hg	mg/m^3			
Provisional limit:	In air:	0.0005 as Hg	mg/m^3	In water:	0.005 as Hg	mg/l

Special precautions: Avoid heating. Respirator.

Comments: Weak base in H_2O. Mercuric Cyanide and its treatment products are not acceptable for underground storage. Recommend recycling.

Name: Mercuric Diammonium Chloride ID no: 503

Formula: $Hg(NH_3)_2Cl_2$ H.I.: 10

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Decomposes g/100cc

Density:	NA	@	Vapor pressure:	NA	@
		@			@
M.P. 300°C.		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Likely to be more volatile than mercuric chloride, although data is lacking. Assumed severe hazard with heating and in air.

Toxicology: Highly toxic by ingestion and inhalation of vapors or dust. May be fatal.

TLV:	In air:	0.05 as Hg	mg/m^3			
Provisional limit:	In air:	0.0005 as Hg	mg/m^3	In water:	0.005 as Hg	mg/l

Special precautions: Avoid heating. Respirator.

Comments: Decomposes in hot H_2O to yield weak acid. Mercuric Diammonium chloride and its treatment products are not acceptable for underground storage. Recycling is recommended.

Name: Mercuric Fulminate ID no: 533

Formula: $Hg(ONC)_2$ H.I.: 21

Solubility: H_2O(cold): 0.01 g/100cc H_2O(hot): 0.2 g/100cc

Density: 4.43 @ 23°C Vapor pressure: NA @

@ @

@ @

Flammability hazard: Extreme. See explosive hazard below.

Explosive hazard: Extreme. Detonates when subjected to very mild thermal, mechanical, or electrical shock.

Volatile hazard: Evolves toxic fumes of NO_x and Hg upon explosive decomposition. Moderate hazard at ambient conditions.

Toxicology: Toxic by ingestion, moderately toxic by inhalation. Insignificant toxicity from skin contact. May be fatal.

TLV: In air: 0.05 mg/m^3 as Hg

Provisional limit: In air: 0.0005 mg/m^3 as Hg In water: 0.005 mg/l as Hg

Special precautions: Disposal at point of origin recommended due to transport hazard.

Comments: Mercuric fulminate and its treatment products are not acceptable for underground storage. Recycling is recommended.

Name: Mercuric Nitrate **ID no:** 255

Formula: $Hg(NO_3)_2 \cdot 1/2H_2O$ **H.I.:** 16

Solubility:	H_2O(cold):	Very Soluble g/100cc	H_2O(hot):	Decomposes	g/100cc
Density:	4.39	@	**Vapor pressure:**	NA	@
		@			@
M.P. 79°C.		@			@

Flammability hazard: Slight to moderate. Can react with other substances to cause a flammable hazard. See explosive hazard below.

Explosive hazard: Slight to moderate. Reacts with alcohols, acetylene, unsaturates and aromatics to form explosive Mercuric Fulminate.

Volatile hazard: Severe. Decomposes on heating evolving toxic NO_x and Hg fumes. Moderate hazard at ambient conditions.

Toxicology: Highly toxic by ingestion and inhalation of dust. Decomposition products on heating include toxic mercury fumes. May be fatal.

TLV:	In air:	0.05 as Hg	mg/m^3			
Provisional limit:	In air:	0.0005 as Hg	mg/m^3	In water:	0.005 as Hg	mg/1

Special precautions: Avoid heating. Respirator.

Comments: Acid in H_2O. May react with alcohols to form explosive mercuric fulminate. Mercuric nitrate and its treatment products are not acceptable for underground storage. Recycling is recommended.

Name: Mercuric Sulfate ID no: 256

Formula: $HgSO_4$ H.I.: 10

Solubility: H_2O(cold): Decomposes g/100cc H_2O(hot): Decomposes g/100cc

Density: 6.47 g/cc @ NA Vapor pressure: NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Releases toxic mercury fumes on heating. Moderate hazard at ambient conditions.

Toxicology: Highly toxic by ingestion and inhalation of dust. Decomposition products on heating include toxic mercury fumes. May be fatal.

TLV: In air: 0.05 as Hg mg/m^3

Provisional limit: In air: 0.0005 as Hg mg/m^3 In water: 0.005 as Hg mg/l

Special precautions: Avoid heating. Respirator.

Comments: Acid in H_2O. Mercuric sulfate and its treatment products are not acceptable for underground storage. Recycling is recommended.

Name: Mercury — **ID no:** 257

Formula: Hg — H.I.: 10

Solubility:	H_2O(cold): Insoluble g/100cc	H_2O(hot):	Insoluble g/100cc
Density:	13.59 g/cc @ 20°C	Vapor pressure:	1.2×10^{-3} mm @ 20°C
	@		1 mm @ 126.2°C
B.P. 356.6°C	@		10 mm @ 184°C

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Moderate volatility at ambient temperatures. Emits toxic fumes when heated.

Toxicology: Highly toxic by ingestion and inhalation of vapor. May be fatal.

TLV:	In air: 0.05 mg/m^3			
Provisional limit:	In air: 0.0005 mg/m^3	In water:	0.005	mg/l

Special precautions: Highly reactive with halogens, hydrogen, sulfide, sulfur, vapor. Avoid heating. Respirator.

Comments: Mercury is not acceptable for underground storage. Recycling is recommended.

Name: Organic Mercury Compounds (Dimethyl Mercury) ID no: 258

Formula: $Hg(CH_3)_2$ H.I.: 16

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): NA g/100cc

Density: 3.07 g/cc @ 20°C Vapor pressure: NA @

@ @

B.P. 96°C @ @

Flammability hazard: Severe. Evolves flammable vapors when heated to decomposition.

Explosive hazard: Slight. Decomposition products may be explosive.

Volatile hazard: Severe. Evolves toxic fumes of mercury when heated to decomposition. Slight hazard at ambient conditions.

Toxicology: Highly toxic by inhalation, ingestion, and absorption through skin. May be fatal.

TLV: In air: 0.01 mg/m^3

Provisional limit: In air: 0.0001 mg/m^3 In water: 0.0005 mg/l

Special precautions:

Comments: Organic mercury compounds and their treatment products are not acceptable for underground storage. Recycling is recommended.

Name: Organic Mercury Compounds (Phenyl Mercuric Acetate) **ID no:** 258

Formula: $C_6H_5HgO_2C_2H_3$ **H.I.:** 16

Solubility: H_2O(cold): Slight g/100cc H_2O(hot): Slight g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

M.P. 149°C

Flammability hazard: Extreme when heated to decomposition.

Explosive hazard: Decomposition products may be explosive.

Volatile hazard: Severe. Emits toxic fumes of Mercury when heated to decomposition. Slight hazard at ambient conditions.

Toxicology: Low toxicity in comparison to other mercuric compounds.

May enter body by inhalation, skin absorption or ingestion. May be fatal.

TLV: In air: 0.01 mg/m^3

Provisional limit: In air: 0.0001 mg/m^3 In water: 0.0005 mg/l

Special precautions: Avoid heating. Protective clothing, respirator.

Comments: Organic mercury compounds and their treatment products are not acceptable for underground treatment. Recycling is recommended.

Name: Methyl Parathion ID no: 274

Formula: $C_8H_{10}O_5SPN$ H.I.: 22

Solubility: H_2O(cold): Very Slight g/100cc H_2O(hot): Slight g/100cc

Density: 1.358 g/cc @ 20°C Vapor pressure: 0.05mm Hg @ 109°C

@ @

M.P. 36°C @ @

Flammability hazard: Severe. Moderately flammable at ambient temperatures. Highly flammable at higher temperatures. 80% methyl parathion in xylene. Has a flash point of 46°C.

Explosive hazard: Severe. May explode @ 120°C.

Volatile hazard: Severe. Should not be heated above 55°C as toxic fumes will be evolved. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion, inhalation, and absorption through skin. Causes headache, blurred vision, nausea, cramps, diarrhea, convulsions, coma. May be fatal.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.01 mg/l

Special precautions: Respirator, protective clothing. Avoid heating.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Nickel Carbonyl ID no: 293

Formula: $Ni(CO)_4$ H.I.: 24

Solubility: H_2O(cold): 0.018 g/100cc H_2O(hot): NA g/100cc

Density: @ Vapor pressure: 261mm Hg @ 15°C

(Liquid) 1.31 @ 25°C 400mm Hg @ 25.8°C

@ 760mm Hg @ 42.5°C

Flammability hazard: Severe. Autoignites on contact with air.

Explosive hazard: Severe. Explodes spontaneously between limits of 3 and 34% by volume in air.

Volatile hazard: Severe. Vaporous at all ambient temperatures.

Toxicology: Extremely toxic by inhalation. It is unknown if nickel carbonyl is absorbed through the skin. Toxic by ingestion. May cause headache, dizziness, nausea, vomiting, fever, cancer. May be fatal. Insidious poison due to lack of immediate symptoms or odor.

TLV: In air: 0.007 mg/m^3

Provisional limit: In air: 0.00007 mg/m^3 In water: 0.00035 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Respirator and protective clothing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional. May have valuable treatment product.

Name: Nickel Cyanide **ID no:** 295

Formula: $Ni(CN)_2$ **H.I.:** 22

Solubility:	H_2O(cold):	Insoluble	g/100cc	H_2O(hot):	Insoluble	g/100cc	
Density:	NA	@		**Vapor pressure:**	NA	@	
		@				@	
		@				@	

Flammability hazard: Severe. Emits highly flammable hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Emits explosive HCN gas on contact with air, moisture, heat, acids, or acid fumes.

Volatile hazard: Severe. Emits hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes. HCN is a toxic, flammable, and explosive gas.

Toxicology: Highly toxic by ingestion. Fumes or dust toxic by inhalation. Moderately toxic (rash) by skin contact. May be fatal.

TLV:	In air:	1.0 as Ni	mg/m^3			
Provisional limit:	In air:	0.01 as Ni	mg/m^3	In water:	0.01 as CN	mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Not acceptable for underground storage without treatment. Treatment products of NiO + NaCl are compatible with rock salt, gypsum, potash, limestone and granite lithology. Treatment products of NiO + $CaCl_2$ are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology. NiO may be valuable treatment product.

Name: Nitrocellulose ID no: 534

Formula: $C_{12}H_{14}(ONO_2)_6O_4$ to $C_{12}H_{17}(ONO_2)_3O_7$ H.I.: 18

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: 1.66 g/cc @ 23°C Vapor pressure: NA @

@ @

@ @

Flammability hazard: Severe. See explosive hazard.

Explosive hazard: Severe. Sensitive to impact, friction, heat and spark.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Nontoxic. However, mixes and solvents may contain benzene which is toxic by inhalation. Considered slight hazard.

TLV: In air: NA mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Nitrogen Mustard ID no: 306

Formula: $(ClCH_2CH_2)_3N$ H.I.: 12

Solubility: H_2O(cold): 0.016 g/100cc H_2O(hot): Decomposes g/100cc

Density: (liquid) 1.24 g/cc @ 20°C Vapor pressure: 0.17mm @ 25°C

(Gas) 7 (Air = 1) @ NA @

@ @

M.P. -4°C B.P. 230-235°C

Flammability hazard: Slight. Reacts violently with dry calcium hypochlorite and may ignite.

Explosive hazard: Slight. May explode on contact with dry calcium hypochlorite.

Volatile hazard: Severe. Combustion yields toxic gaseous hydrogen chloride and nitrogen oxides. Fumes in air.

Toxicology: Highly toxic by inhalation, contact with skin and eyes, and ingestion. A chemical warfare agent. Can blister the skin. May be fatal.

TLV: In air: .0003 mg/m^3 Estimated

Provisional limit: In air: $3x10^{-6}$ mg/m^3 Estimated In water: $1.5x10^{-5}$ mg/l Estimated

Special precautions: Respirator, protective clothing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Nitroglycerine ID no: 307

Formula: $C_3H_5(ONO_2)_3$ H.I.: 21

Solubility: H_2O(cold): 0.18 g/100cc H_2O(hot): g/100cc

Density:	1.5918 g/cc @ 25°C	Vapor pressure:	2mm	@ 125°C
	@		50mm	@ 180°C
	@		Explodes	@ 218°C

M.P. 13.5°C. Decomposes @ 50-60°C.

Flammability hazard: Severe. See explosive hazard below. Ignites @ 150-160°C. Explodes when burning.

Explosive hazard: Severe. Very sensitive to mechanical or thermal shock and freezing.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by ingestion, inhalation, and skin absorption.

TLV: In air: 0.2 mg/m^3

Provisional limit: In air: 0.002 mg/m^3 In water: 0.1 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Avoid freezing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Parathion ID no: 321

Formula: $C_{10}H_{14}NO_5PS$ H.I.: 22

Solubility: H_2O(cold): .0024 g/100cc H_2O(hot): NA g/100cc

Density: 1.26 @ 25/4°C Vapor pressure: 0.6mm @ 157-162°C

@ 0.57×10^{-5}mm @ 20°C

@ @

M.P. 6°C. B.P. 375°C.

Flammability hazard: Severe. Highly flammable if heated above 100°C.

Explosive hazard: Severe. May explode if heated above 100°C.

Volatile hazard: Severe. Emits toxic fumes of oxides of nitrogen and sulphur when heated to decomposition. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by inhalation, ingestion and absorption through skin. May cause headache, blurred vision, nausea, cramps, diarrhea, convulsions, coma. May be fatal.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 In water: 0.005 mg/l

Special precautions: Approved respirator and protective clothing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Pentaborane ID no: 505

Formula: B_5H_9 H.I.: 25

Solubility: H_2O(cold): Hydrolyzes g/100cc H_2O(hot): Hydrolyzes g/100cc

Density: @ Vapor pressure: 66mm Hg @ 0°C

(Liquid) 0.61 g/cc @ 0°C @

(Gas) 2.2 (Air = 1)@ 0°C @

B.P. 58.4°C Flash point 30°C

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Very unstable in the presence of a wide variety of impurities if subjected to thermal or mechanical shock.

Volatile hazard: Severe. Evolves toxic fumes in air or when heated. Contact with water liberates H_2 gas.

Toxicology: Highly toxic. Emergency exposure limit (EEL) 25 ppm in air for 5 minutes. Toxic by inhalation and ingestion. May cause dizziness, injury to liver and kidneys.

TLV: In air: 0.01 mg/m^3

Provisional limit: In air: 0.0001 mg/m^3 In water: 0.0005 mg/l

Special precautions: Respirator, protective clothing. Avoid contact with air, water, or heat.

Comments: Contact with water will release explosive hydrogen. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Pentachlorophenol **ID no:** 322

Formula: Cl_5C_6OH **H.I.:** 7

Solubility:	H_2O(cold):	Insoluble g/100cc	H_2O(hot):	Insoluble g/100cc	
				0.12mm Hg @	100°C
Density:	1.978 g/cc @	22/4°C	**Vapor pressure:**	5.5mm Hg @	160°C
	@			50mm Hg @	220°C
	@			550mm Hg @	300°C

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Heating to decomposition evolves chloride fumes. (Decomposition temperature 310°C) Nonvolatile at ambient conditions.

Toxicology: Highly toxic by inhalation, ingestion, and skin contact. Toxic chloride fumes evolved on heating to decomposition. May cause liver and kidney injury.

TLV: **In air:** 0.5 mg/m^3

Provisional limit: **In air:** 0.005 mg/m^3 **In water:** 0.25 mg/1

Special precautions: Avoid heating. Respirator, protective clothing.

Comments: Not acceptable for underground storage without treatment. Underground storage of products is optional.

Name: Pentaerytritol Tetranitrate (PETN) **ID no:** 319

Formula: $C(CH_2NO_3)_4$ **H.I.:** 20

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density:	1.77 g/cc	@	20°C	**Vapor pressure:**	NA	@
		@				@
		@				@

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. May detonate when subjected to a flame or percussion. Explosion temperature 211°C after 10 seconds.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Moderate toxicity by ingestion, inhalation and absorption through skin. May cause headache, weakness, and fall in blood pressure.

TLV: In air: 2 mg/m^3

Provisional limit: In air: 0.02 mg/m^3 In water: 0.1 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Perchloric Acid (72%) ID no: 324

Formula: $HClO_4$ H.I.: 24

Solubility: H_2O(cold): Very Soluble g/100cc H_2O(hot): Very soluble g/100cc

Density: 1.764 g/cc @ 20°C Vapor pressure: NA @

@ @

@ @

Flammability hazard: Severe. A strong oxidizing acid when heated. Could ignite other oxidizable materials.

Explosive hazard: Severe. Anhydrous perchloric acid decomposes explosively in storage and with trace contaminants. Highly reactive with reducing substances and active metals.

Volatile hazard: Severe. Emits toxic and corrosive fumes of HCL.

Toxicology: Liquid causes severe burns to eyes and skin. Inhalation of mist or spray irritates respiratory tract.

TLV: In air: NA mg/m^3

Provisional limit: In air: 0.01 Estimated mg/m^3 In water: 0.05 Estimated mg/l

Special precautions: Avoid heating. Respirator and protective clothing.

Comments: Acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name:	Perchloryl Fluoride	**ID no:**	326
Formula:	ClO_3F	**H.I.:**	18

Solubility: H_2O(cold): 0.01 g/100cc @ 25°C H_2O(hot): NA g/100cc

Density: 1.392 g/l	@	**Vapor pressure:**	@
	@		@
M.P. -148°C	@ B.P. -47°C		@

Flammability hazard: Moderate. A powerful oxidizer. Could ignite oxidizable materials.

Explosive hazard: Moderate. On contact with readily oxidized substances may become shock sensitive.

Volatile hazard: Severe. A toxic gas at ambient temperatures.

Toxicology: Moderate toxicity by inhalation and absorption through skin. May cause anemia.

TLV: **In air:** 2.50 mg/m^3

Provisional limit: **In air:** 0.025 mg/m^3 **In water:** 0.61-1.7 mg/l

Special precautions: Respirator, protective clothing.

Comments: Acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Picric Acid ID no: 338

Formula: $(NO_2)_3C_6H_2OH$ H.I.: 21

Solubility: H_2O(cold): 1.17 g/100cc @ 20°C H_2O(hot): 7.1 g/100cc @ 100°C

Density: 1.76 g/cc @ 23°C Vapor pressure: @

@ @

@ Explosion temp. test value 322°C @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. A high explosive and may undergo detonation when subjected to a flame or percussion.

Volatile hazard: Severe. Emits highly toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: May cause nausea, vomiting, diarrhea, and convulsions. Toxic by inhalation and ingestion. Moderately toxic by absorption through skin.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 In water: 0.005 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive explosive. Respirator, protective clothing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Potassium Arsenite **ID no:** 341

Formula: $KAsO_2$ **H.I.:** 5

Solubility: H_2O(cold): Soluble g/100cc H_2O(hot): Soluble g/100cc

Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Extremely toxic by ingestion, inhalation, and skin absorption. May be fatal.

TLV:	**In air:**	0.5 as As	mg/m^3			
Provisional limit:	**In air:**	0.005 as As	mg/m^3	**In water:**	0.05 as As	mg/l

Special precautions: Respirator, protective clothing.

Comments: Base in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), and limestone lithology.

Name: Potassium Chromate **ID no:** 343

Formula: K_2CrO_4 **H.I.:** 10

Solubility: H_2O(cold): 62.9 g/100cc H_2O(hot): 79.2 @ 100°C g/100cc

Density: 2.732 g/cc @ 20°C **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Moderate. A strong oxidizing agent, can ignite oxidizable materials.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. Corrosive on contact with skin and mucous membranes. Hexavalent chromates (Cr^{+6}) more toxic than trivalent chromates. May cause ulcers and cancer.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 as CrO_3 In water: 0.05 mg/l as CrO_3

Special precautions: Respirator, protective clothing.

Comments: Weak base in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Potassium Cyanide   ID no: 344

Formula: KCN   H.I.: 24

Solubility: H_2O(cold): 72 g/100cc @ 25°C H_2O(hot): g/100cc

Density: 1.55 g/cc @ 20°C   Vapor pressure: NA @
1.56 g/cc @ 25°C   @
@   @

Flammability hazard: Severe. Evolves flammable hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive hydrogen cyanide gas. See flammability hazard above.

Volatile hazard: Severe. Evolves hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes. HCN gas is toxic, flammable, and explosive.

Toxicology: Extremely toxic by ingestion, inhalation of dust and absorption through skin. Decomposition product extremely toxic. May be fatal.

TLV: In air: 5 as CN mg/m^3

Provisional limit: In air: 0.05 as CN mg/m^3 In water: 0.01 as CN mg/l

Special precautions: Respirator, protective clothing. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Base in H_2O. Not acceptable for underground storage without Treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Potassium Dichromate ID no: 345

Formula: $K_2Cr_2O_7$ H.I.: 10

Solubility: H_2O(cold): 4.9 g/100cc @ 0°C H_2O(hot): 102 g/100cc @ 100°C

Density: 2.68 g/cc @ 25°C Vapor pressure: NA @

@ @

@ @

Flammability hazard: Moderate. A powerful oxidant which can ignite oxidizable material.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile. Decomposes @ 500°C.

Toxicology: Highly toxic by ingestion and inhalation of dust. Corrosive on contact w/skin and mucous membranes. Hexavalent chromium (Cr^{+6}) more toxic than trivalent (Cr^{+3}). May cause ulcers and lung cancer.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 as CrO_3 In water: 0.05 mg/l as Cr

Special precautions: Respirator, protective clothing.

Comments: Weak acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Potassium Dinitrobenzfuroxan (KDNBF) **ID no:** 536

Formula: $C_8H_4N_4O_6K$ **H.I.:** 20

Solubility: H_2O(cold): 0.245 g/100cc @ 30°C H_2O(hot): Slight g/100cc

Density: 2.21 g/cc @ 23°C Vapor pressure: NA @

@ @

@ Explodes at 210°C @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Detonates when subjected to very mild thermal or mechanical shock, or flame.

Volatile hazard: Severe. Emits toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Mildly toxic by ingestion, inhalation of dust, and skin contact. May irritate the skin.

TLV: In air: Not established mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive explosive.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Silver Acetylide **ID no:** 537

Formula: Ag_2C_2 **H.I.:** 20

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Stronger explosive properties than cuprous acetylide. Sensitive to thermal or mechanical shock or friction.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Not established. Probably low as it has low solubility in body fluids. However, assumed severe hazard.

TLV: In air: Not established mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/1

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive explosive.

Comments: Not acceptable for underground storage. Further study is needed for treatment procedure.

Name: Silver Azide ID no: 538

Formula: AgN_3 H.I.: 20

Solubility: H_2O(cold): $0.039x10^{-5}$ g/100cc H_2O(hot): 0.01 g/100cc

Density: 4.8 g/cc @ Vapor pressure: NA @
@ @
@ @

M.P. 250°C. Explosion Temperature 297-300°C.

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. A detonating agent sensitive to heat, impact, electrical discharge or friction.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by inhalation of dust and absorption through skin.

TLV: In air: 0.01 mg/m^3 as Ag

Provisional limit: In air: 0.0001 mg/m^3 as Ag In water: 0.05 mg/1 as Ag

Special precautions: Treatment at point of origin is recommended due to transport hazard.

Comments: Not acceptable for underground storage. Further study is needed for treatment procedure. No current known manufacturers in U.S.

Name: Silver Cyanide **ID no:** 370

Formula: AgCN **H.I.:** 22

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: 3.95 g/cc @ 20°C Vapor pressure: NA @

@ @

@ @

Flammability hazard: Severe. Evolves flammable hydrogen cyanide (gas) on contact with air, moisture, heat, acids, or acid fumes.

Explosive hazard: Severe. Evolves explosive hydrogen cyanide gas. See flammability hazard above.

Volatile hazard: Severe. Evolves hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes. HCN gas is toxic, flammable, and explosive.

Toxicology: Extremely toxic by ingestion, inhalation. Skin irritant. May be fatal.

TLV: In air: 0.01 as Ag mg/m^3

Provisional limit: In air: 0.0001 as Ag mg/m^3 In water: 0.01 as CN mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Not acceptable for underground storage without treatment. Treatment products are compatible in gypsum, shale (1) and (2), limestone, and granite lithologies. Treatment products may be valuable.

Name: Silver Styphnate   **ID no:** 539

Formula: $Ag_2C_6HN_3O_8$ **H.I.:** 21

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @   **Vapor pressure:** NA @

@   @

@   @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Undergoes detonation when subjected to very mild thermal, mechanical, or electrical shock.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: No data available. Thought to be only slightly toxic. Assumed moderate hazard by ingestion or inhalation.

TLV: In air: 0.01 as Ag mg/m^3

Provisional limit: In air: 0.0001 as Ag mg/m^3 In water: 0.05 as Ag mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive explosive.

Comments: Not acceptable for underground storage. Further study is needed for treatment procedure.

Name: Silver Tetrazene ID no: 540

Formula: NA H.I.: 21

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ Vapor pressure: NA @
@ @
@ @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. Undergoes detonation when subjected to very mild thermal, mechanical, or electric shock.

Volatile hazard: Severe. May emit toxic gases upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: No data available. Thought to be only slightly toxic. Assumed toxic through ingestion and inhalation and thus a moderate hazard.

TLV: In air: 0.01 as Ag mg/m^3

Provisional limit: In air: 0.0001 as Ag mg/m^3 In water: 0.05 as Ag mg/1

Special precautions: Treatment at point of origin recommended due to transport hazard. Sensitive explosive.

Comments: Not acceptable for underground storage. Further study is needed for treatment procedure.

Name: Smokeless Gunpowder[*] ID no: 541

Formula: Varies H.I.: 14

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ Vapor pressure: NA @

@ @

@ @

Flammability hazard: Severe. See explosive hazard below.

Explosive hazard: Severe. A propellant for firearms.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Moderately toxic by inhalation of dust and ingestion. May be a skin irritant.

TLV: In air: NA mg/m^3

Provisional limit: In air: NA mg/m^3 In water: NA mg/l

Special precautions: Treatment at point of origin recommended, due to transport hazard. Explosive.

Comments: [*] Primarily nitrocellulose (single base propellant). Double base propellant also contains nitroglycerine. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Sodium Arsenate ID no: 376

Formula: Na_2HAsO_4 H.I.: 5

Solubility: H_2O(cold): 61 g/100cc H_2O(hot): 100 g/100cc

Density: 1.87 g/cc @ NA Vapor pressure: NA @

@ @

@ @

MP 125°C

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. May be fatal.

TLV:	In air:	0.5 as As	mg/m^3			
Provisional limit:	In air:	0.005 as As	mg/m^3	In water:	0.05 as As	mg/l

Special precautions: Respirator.

Comments: Base in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, and limestone lithology.

Name: Sodium Arsenite ID no: 377

Formula: Na_3AsO_3 and $NaAsO_2$ H.I.: 5

Solubility: H_2O(cold): Very soluble g/100cc H_2O(hot): Very soluble g/100cc

Density: 1.87 g/cc @ Vapor pressure: NA @

@ @

@ @

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. May be fatal.

TLV: In air: 0.5 as As mg/m^3

Provisional limit: In air: 0.005 as As mg/m^3 In water: 0.05 as As mg/1

Special precautions: Respirator.

Comments: Base in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, and limestone lithology.

Name: Sodium Cacodylate **ID no:** 382

Formula: $C_2H_6O_2AsNa$ **H.I.:** 9

Solubility: **H_2O(cold):** 200 g/100cc **H_2O(hot):** Decomposes g/100cc

Density:	NA	@	**Vapor pressure:**	NA	@
		@			@
		@			@

Flammability hazard: Slight. May evolve flammable gases when heated to decomposition.

Explosive hazard: Slight. May evolve explosive gases when heated to decomposition.

Volatile hazard: Severe. When heated to decomposition may evolve gaseous hydrocarbons and H_2. Nonvolatile at ambient conditions.

Toxicology: Highly toxic by ingestion and inhalation of spray or dust. May be fatal.

TLV:	**In air:**	0.5 as As	mg/m^3			
Provisional limit:	**In air:**	0.005 as As	mg/m^3	**In water:**	0.05 as As	mg/l

Special precautions: Respirator. Avoid heating.

Comments: Base in H_2O. Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, and limestone lithology.

Name: Sodium Chromate ID no: 386

Formula: Na_2CrO_4 H.I.: 10

Solubility: H_2O(cold): 87.3 g/100cc @ 30°C H_2O(hot): NA g/100cc

Density: 2.71 g/cc @ NA Vapor pressure: NA @

@ @

@ @

Flammability hazard: Moderate. A powerful oxidant that may ignite flammable materials. Highly reactive with reducing agents.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. Highly corrosive on contact w/skin and mucous membrane. May cause ulcers and lung cancer.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 as CrO_3 mg/m^3 In water: 0.05 as Cr mg/l

Special precautions: Respirator, protective clothing.

Comments: Weak base in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Sodium Cyanide ID no: 387

Formula: NaCN H.I.: 24

Solubility: H_2O(cold): 48 g/100cc @ 10°C H_2O(hot): 82 g/100cc @ 35°C

Density: 1.6 g/cc @ 20°C

Vapor pressure: 0.76mm Hg@ 800°C

3.34mm Hg@ 900°C

MP 560°C

Flammability hazard: Severe. Emits flammable hydrogen cyanide fumes. See below.

Explosive hazard: Severe. Evolves explosive hydrogen cyanide fumes. See below.

Volatile hazard: Severe. Evolves HCN gas on contact with air, moisture, heat, acids, or acid fumes. HCN is toxic, flammable, and explosive.

Toxicology: Highly toxic by ingestion, inhalation of fumes or dust. Moderately toxic on skin contact. May be fatal.

TLV: In air: 5.0 mg/m³ as CN

Provisional limit: In air: 0.05 mg/m³ as CN In water: 0.01 mg/1 as CN

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Base in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Sodium Dichromate **ID no:** 379

Formula: $Na_2Cr_2O_7$ **H.I.:** 10

Solubility: H_2O(cold): 238 g/100cc @ 0°C H_2O(hot): 508 @ 80°C g/100cc

Density: 2.52 g/cc @ 13°C **Vapor pressure:** NA @

@ @

Decomposition temperature 400°C @ @

Flammability hazard: Moderate. A powerful oxidizing material which may ignite combustible material. Highly reactive with reducing agents.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. Highly corrosive on contact w/skin and mucous membrane. May cause ulcers and lung cancer.

TLV: In air: 0.1 mg/m^3

Provisional limit: In air: 0.001 mg/m^3 as CrO_3 In water: 0.05 mg/l as Cr

Special precautions: Respirator, protective clothing.

Comments: Weak acid in H_2O. Not acceptable for underground storage without treatment. Treatment products are compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone and granite lithology.

Name: Sulfur Mustard ID no: 543

Formula: $(ClCH_2CH_2)_2S$ H.I.: 24

Solubility: H_2O(cold): 800 g/100cc @ 20°C H_2O(hot): NA g/100cc

Density: 1.274 g/cc (Liquid) @
5.4 (air=1) (Gas) @ 20°C
MP 13.5°C BP 227.8°C @

Vapor pressure: 0.05mm Hg @ 10°C
0.1mm Hg @ 20°C
0.2mm Hg @ 30°C

Flammability hazard: Severe. Decomposition products are flammable.

Explosive hazard: Decomposition products may be explosive.

Volatile hazard: Severe. Fumes in air. Evolves toxic, flammable and possibly explosive gases when heated to decomposition.

Toxicology: Highly toxic by contact with skin and mucous membrane. A blister gas. Highly toxic by inhalation and ingestion. May be fatal.

TLV: In air: 0.0003 mg/m^3 Estimated

Provisional limit: In air: 3×10^{-6} mg/m^3 Estimated In water: 1.5×10^{-5} mg/l Estimated

Special precautions: Respirator, protective clothing. Impure sulphur mustard will corrode iron and steel containers with a pressure rise.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: TNT (Trinitrotoluene) ID no: 418

Formula: $C_7H_5O_6N_3$ H.I.: 19

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble g/100cc

Density: 1.65 g/cc @ 20°C Vapor pressure: 0.042mm Hg@ 80°C

@ 0.106mm Hg@ 100°C

MP 81°C @ Autoignition temp 570°C (Explodes) @

Flammability hazard: Severe. See explosive hazard.

Explosive hazard: Severe. A high explosive, normally requiring initiation by a primary explosive to detonate but may detonate when subjected to a flame or percussion.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Toxic by inhalation of fumes and ingestion. Skin contact causes staining and in some individuals, dermatitis.

TLV: In air: 1.5 mg/m³

Provisional limit: In air: 0.015 mg/m³ In water: 0.075 mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Explosive.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Tear Gas (CN) or Chloroacetophenone **ID no:** 422,107

Formula: C_8H_7OCl **H.I.:** 12

Solubility:	H_2O(cold):	Insoluble	g/100cc	H_2O(hot): NA	g/100cc
Density:	1.321 g/cc	@ 20°C	**Vapor pressure:**	0.012mm Hg @ 0°C	
		@		0.16mm Hg @ 50°C	
MP 58-59°C BP 247°C		@		@	

Flammability hazard: Slight. Decomposition products may be flammable.

Explosive hazard: Slight. Decomposition products may be explosive.

Volatile hazard: Severe. Emits toxic fumes in air and when heated. When heated to decomposition evolves toxic fumes of chlorides and possibly H_2. Reacts with steam to evolve HCL fumes.

Toxicology: Highly toxic by contact with skin and mucous membranes especially eyes. Toxic by inhalation and ingestion.

TLV:	**In air:** 0.30	mg/m^3		
Provisional limit:	**In air:** 0.003	mg/m^3	**In water:** NA	mg/l

Special precautions: Respirator, protective clothing. Avoid heating.

Comments: Will react with water or steam to produce toxic and corrosive fumes. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Tear Gas (CS) (2-Chlorobenzylidene malononitrile) **ID no:** 423

Formula: $C_{10}H_6N_2Cl$ **H.I.:** 11

Solubility: H_2O(cold): NA g/100cc H_2O(hot): NA g/100cc

Density: NA @ **Vapor pressure:** NA @

@ @

MP 95°C BP 310-315°C @ @

Flammability hazard: Slight. Products of hydrolysis w/moisture may be flammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Severe. Used as an aerosol for riot control. Forms highly toxic solid with moisture. When heated to decomposition emits toxic fumes.

Toxicology: Highly toxic by contact w/skin and mucous membranes. Hydrolyzes w/moisture to yield highly toxic malonic acid nitrile.

TLV: **In air:** 0.40 mg/m^3

Provisional limit: **In air:** 0.004 mg/m^3 **In water:** 0.020 mg/l

Special precautions: Avoid heating and contact with moisture. Respirator, protective clothing.

Comments: Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Tetrazene **ID no:** 542

Formula: $C_2H_8ON_9$ **H.I.:** 18

Solubility: H_2O(cold): Insoluble g/100cc H_2O(hot): Insoluble (Decomposes) g/100cc

Density: 1.05 g/cc @ 3000 psig* **Vapor pressure:** NA @

@ @

@ @

Flammability hazard: Severe. Easily ignited.

Explosive hazard: Severe. Used as an initiating explosive in ignition caps. Sensitive to very mild thermal, mechanical or electrical shock.

Volatile hazard: Severe. May emit toxic fumes upon explosive decomposition. Nonvolatile at ambient conditions.

Toxicology: Unknown. Assumed to have only mildly toxic effects.

TLV: **In air:** NA mg/m^3

Provisional limit: **In air:** NA mg/m^3 **In water:** NA mg/l

Special precautions: Treatment at point of origin recommended due to transport hazard. Explosive.

Comments: *A "fluffy" solid, hence the density determination was made under pressure. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: VX (Persistent Nerve Gas) **ID no:** 288

Formula: $C_{11}H_{26}O_2SNP$ **H.I.:** 13

Solubility:	H_2O(cold):	NA	g/100cc	H_2O(hot):	NA	g/100cc

Density:	1.1 g/cc (Liquid)	@ 25°C	Vapor pressure:	12-14 mg/m^3	@ 25°C
		@			@
BP 300°C		@			@

Flammability hazard: Slight. May evolve flammable H_2S when heated to decomposition.

Explosive hazard: Slight. May evolve explosive H_2S when heated to decomposition.

Volatile hazard: Low volatility, but extreme toxicity makes even low volatility an extreme toxic hazard at ambient temperatures. Vapor pressure increases with heating. When heated to decomposition may evolve toxic fumes including H_2S.

Toxicology: Extremely toxic by ingestion, inhalation, and absorption through skin. A "nerve gas". May be fatal.

TLV:	In air:	0.0003 mg/m^3			
Provisional limit:	In air:	*Estimated 0.000003 mg/m^3	In water:	NA	mg/l

Special precautions: Respirator, protective clothing. Avoid heating.

Comments: Much information on this compound is classified. *Maximum concentration by U.S. Army recommendation. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

Name: Zinc Arsenate **ID no:** 453

Formula: $Zn_3(AsO_4)_2$ **H.I.:** 2

Solubility:	H_2O(cold):	Insoluble g/100cc	H_2O(hot):	Insoluble	g/100cc
Density:	3.309 g/cc	@ 15°C	Vapor pressure:	NA	@
		@			@
		@			@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Extremely toxic by ingestion and inhalation of dust. May be fatal.

TLV:	In air:	0.5 as As	mg/m^3			
Provisional limit:	In air:	0.005 as As	mg/m^3	In water:	0.05 as As	mg/l

Special precautions: Respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2). limestone, and granite lithology.

Name: Zinc Arsenite **ID no:** 454

Formula: $Zn(AsO_2)_2$ **H.I.:** 3

Solubility: **H_2O(cold):** Low g/100cc **H_2O(hot):** NA g/100cc

Density: NA	@	**Vapor pressure:** NA	@
	@		@
	@		@

Flammability hazard: Nonflammable.

Explosive hazard: Nonexplosive.

Volatile hazard: Nonvolatile.

Toxicology: Highly toxic by ingestion and inhalation of dust. May be fatal.

TLV:	**In air:**	0.5 as As	mg/m^3			
Provisional limit:	**In air:**	0.005 as As	mg/m^3	**In water:**	0.05 as As	mg/l

Special precautions: Respirator.

Comments: Acceptable for underground storage without treatment. Compatible with rock salt, gypsum, potash, shale (1), shale (2), limestone, and granite lithology.

Name: Zinc Cyanide **ID no:** 457

Formula: $Zn(CN)_2$ **H.I.:** 16

Solubility: H_2O(cold): 0.0005 g/100cc H_2O(hot): NA g/100cc

Density: 1.852 g/cc @ Vapor pressure: NA @

@ @

@ Decomposition temp. 800°C @

Flammability hazard: Severe. Evolves flammable hydrogen cyanide in even weak acid environments. CO_2 in air is sufficient to evolve hydrogen cyanide.

Explosive hazard: Severe. May evolve hydrogen cyanide on decomposition, resulting in an explosive hazard. See flammability hazard above.

Volatile hazard: Severe. Evolves hydrogen cyanide gas on contact with air, moisture, heat, acids, or acid fumes.

Toxicology: Extremely toxic by ingestion and inhalation of dust. Moderately toxic by long term skin contact. May be fatal.

TLV: In air: 5.0 as CN mg/m^3

Provisional limit: In air: 0.05 as CN mg/m^3 In water: 0.01 as CN mg/l

Special precautions: Respirator. Avoid contact with air, moisture, heat, acids, or acid fumes.

Comments: Weak base in H_2O. Not acceptable for underground storage without treatment. Treatment products are essentially nontoxic. Underground storage of products is optional.

APPENDIX B-2

HAZARD INDEX OF CANDIDATE WASTES

Hazard Index 10-25: Not Acceptable - Must Be Treated (All Substances Containerized)
Hazard Index 6-9: Optional Treatment
Hazard Index 0-5: Containerization Only

Substance	I.D. No.	Flammable 0 to 7	Explosive 0 to 7	Evolve Gas in air or Water 0 to 3	Evolve Gas with heat 0 to 3	Soluble in H_2O 0 to 2	Toxic 0 to 3	Hazard Index (H.I.)
Acrolein	8	7	7	0	3	2	3	22
Aldrin	13	1	1	0	3	1	3	9
Ammonium Chromate	21	7	0	3	3	2	3	18
Ammonium Dichromate	22	7	0	3	3	2	3	18
Ammonium Picrate	27 28	7	7	0	3	2	2	21
Antimony Pentafluoride	36	0	0	3	3	2	3	11
Antimony Trifluoride	43	0	0	3	3	2	3	11
Arsenic Trichloride	50	0	0	3	3	2	3	11
Arsenic Trioxide	51	0	0	0	3	2	2	7
Benzene Hexachloride	55	1	1	0	3	1	2	8
Boron Hydrides	61 505	7	7	3	3	2	3	25
Bromine Pentafluoride	66	7	7	3	3	2	3	25
Cacodylic Acid	80	1	1	0	3	2	2	9
Cadmium (as a solid)	81	0	0	0	2	0	1	3
Cadmium, Powdered	82	7	7	0	2	0	2	18
Cadmium Chloride	83	0	0	0	0	2	3	5
Cadmium Cyanide	84	7	7	3	3	2	2	24
Cadmium Fluoride	478	0	0	0	0	2	3	5
Cadmium Nitrate	479	5	5	0	2	2	3	17
Cadmium Oxide	85	0	0	0	0	0	2	2

Substance	I.D. No.	Flammable 0 to 7	Explosive 0 to 7	Evolve Gas in air or Water 0 to 3	Evolve Gas with heat 0 to 3	Soluble in H_2O 0 to 2	Toxic 0 to 3	Hazard Index (H.I.)
Cadmium Phosphate	86	0	0	0	0	0	2	2
Cadmium Potassium Cyanide	480	7	7	3	3	2	2	24
Cadmium Sulfate	481	0	0	0	0	2	3	5
Calcium Arsenate	87	0	0	0	0	1	2	3
Calcium Arsenite	88	0	0	0	1	1	2	4
Calcium Cyanide	91	7	7	3	3	2	2	24
Chlordane	484	1	1	3	3	1	3	12
Chlorine	105	5	5	3	3	2	3	21
Chlorine Trifluoride and Pentafluoride	106	7	7	3	3	2	3	25
Chromic Acid	114	5	5	0	0	2	3	15
Copper Acetoarsenite	490	1	1	0	3	1	3	9
Copper Acetylide	517	7	7	0	3	0	2	19
Copper Arsenate	119	0	0	0	0	0	2	2
Copper Chlorotetrazole	518	7	7	0	3	1	2	20
Copper Cyanide	120	7	7	3	3	0	2	22
Cuprous Cyanide	128	7	7	3	3	0	2	22
Cyanides	129	7	7	3	3	2	2	24
DDD	136	1	1	0	3	1	3	9
DDT	137	1	1	0	3	1	3	9
Demeton	491	1	1	0	3	1	3	9
Detonators & Primers	520	7	7	0	3	0	0	17
Diazodinitrophenol (DDNP)	521	7	7	0	3	1	2	20
2, 4-D	135	1	1	0	3	1	2	8
Dieldrin	149	1	1	0	3	1	3	9
Dimethyl Sulfate	160	5	5	3	3	1	3	20

Substance	I.D. No.	Flammable 0 to 7	Explosive 0 to 7	Evolve Gas in air or Water 0 to 3	Evolve Gas with heat 0 to 3	Soluble in H_2O 0 to 2	Toxic 0 to 3	Hazard Index (H.I.)
Dinitro Cresols	162	4	4	0	1	1	3	13
Dinitrotoluene (DNT)	165	7	7	0	3	1	3	21
Dipentaerythritol Hexanitrate (DPEHN)	522	7	7	0	3	1	2	20
Endrin	170	1	1	0	3	1	3	9
Fluorine	200	6	2	3	3	2	3	19
GB	287	0	0	2	3	2	3	10
Gellatinized Nitrocellulose	523	7	7	0	3	0	1	18
Glycol Dinitrate	525	7	7	1	3	2	3	23
Gold Fulminate	526	7	7	0	3	0	3	20
Guthion	495	1	1	0	3	1	3	9
Heptachlor	496	1	1	0	3	1	3	9
Hydrogen Sulfide	221	7	7	3	3	2	2	24
Lead Arsenate	235	0	0	0	1	1	2	4
Lead Arsenite	236	0	0	0	1	0	2	3
Lead Azide	529	7	7	0	3	2	2	21
Lead Cyanide	239	7	7	3	3	1	2	23
Lead 2, 4 Dinitroresorcinate (LDNR)	530	7	7	0	3	0	2	19
Lead Styphnate	531	7	7	0	3	0	3	20
Lewisite	243	0	0	3	3	2	3	11
Magnesium Arsenite	245	0	0	0	0	1	3	4
Manganese Arsenate	500	0	0	0	0	1	2	3
Mannitol Hexanitrate	532	7	7	0	3	0	1	18
Mercuric Chloride	253	0	0	1	3	2	3	10

Substance	I.D. No.	Flammable 0 to 7	Explosive 0 to 7	Evolve Gas in air or Water 0 to 3	Evolve Gas with heat 0 to 3	Soluble in H_2O 0 to 2	Toxic 0 to 3	Hazard Index (H.I.)
Mercuric Cyanide	254	7	7	3	3	2	3	25
Mercuric Diammonium Chloride	503	0	0	3	3	1	3	10
Mercuric Fulminate	533	7	7	2	3	0	2	21
Mercuric Nitrate	255	3	3	2	3	2	3	16
Mercuric Sulfate	256	0	0	2	3	2	3	10
Mercury	257	0	0	2	3	2	3	10
Organic Mercury Cmpds.	258	7	1	1	3	1	3	16
Methyl Parathion	274	7	7	0	3	2	3	22
Nickel Carbonyl	293	7	7	3	3	1	3	24
Nickel Cyanide	295	7	7	3	3	0	2	22
Nitrocellulose	534	7	7	0	3	0	1	18
Nitrogen Mustard	306	1	1	3	3	1	3	12
Nitroglycerin	307	7	7	0	3	1	3	21
Parathion	321	7	7	0	3	2	3	22
Pentaborane	505	7	7	3	3	2	3	25
Pentachlorophenol	322	0	0	0	3	1	3	7
Pentaerythritol Tetranitrate (PETN)	319	7	7	0	3	0	3	20
Perchloric Acid (72% strength)	324	7	7	3	3	2	2	24
Perchloryl Fluoride	326	5	5	3	3	1	1	18
Picric Acid	338	7	7	0	3	1	3	21
Potassium Arsenite	341	0	0	0	0	2	3	5
Potassium Chromate	343	5	0	0	0	2	3	10
Potassium Cyanide	344	7	7	3	3	2	2	24

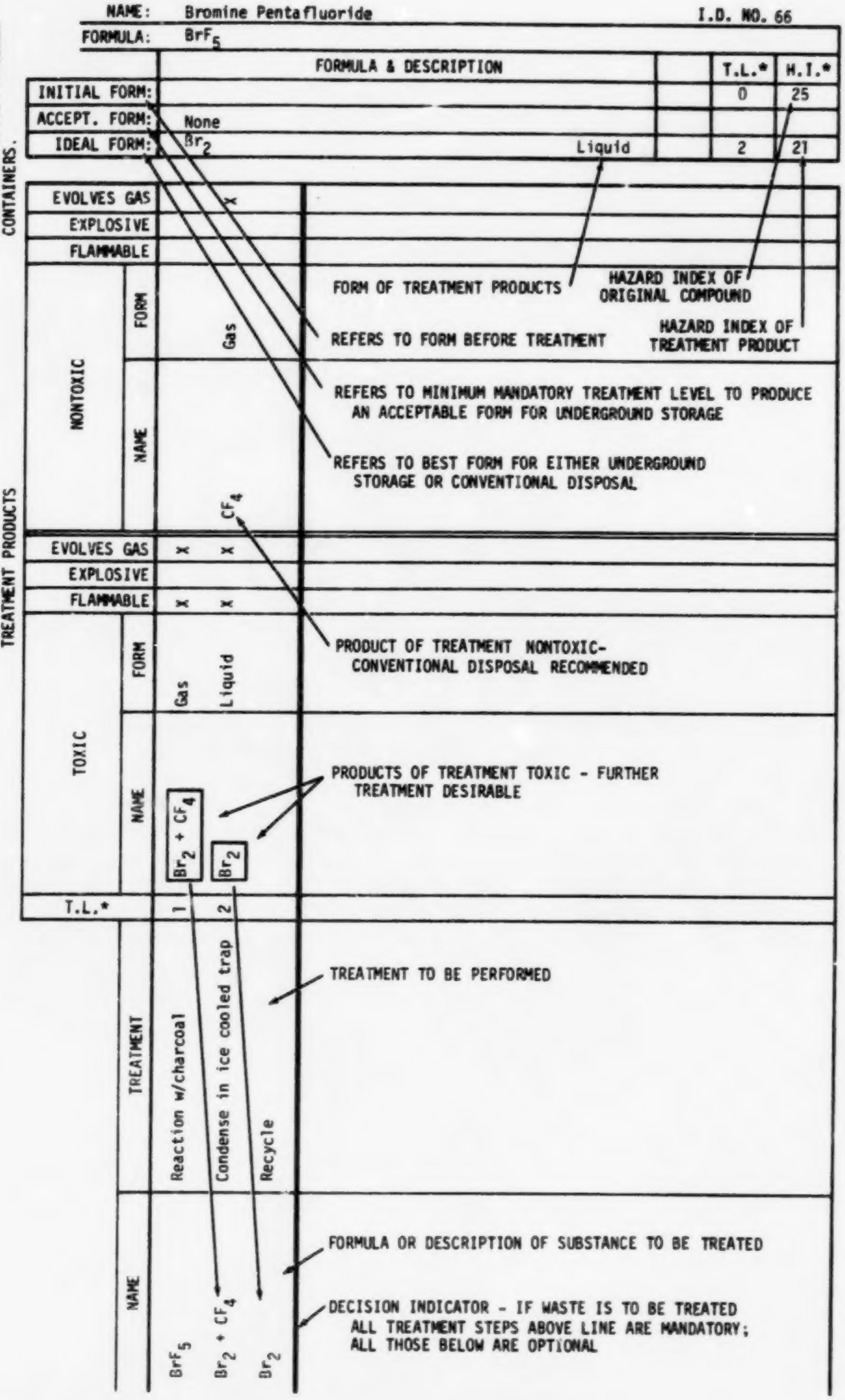
Substance	I.D. No.	Flammable 0 to 7	Explosive 0 to 7	Evolve Gas in air or Water 0 to 3	Evolve Gas with heat 0 to 3	Soluble in H_2O 0 to 2	Toxic 0 to 3	Hazard Index (H.I.)
Potassium Dichromate	345	5	0	0	0	2	3	10
Potassium Dinitrobenzfuroxan (KDNBF)	536	7	7	0	3	1	2	20
Silver Acetylide	537	7	7	0	3	0	3	20
Silver Azide	538	7	7	0	3	0	3	20
Silver Cyanide	370	7	7	3	3	0	2	22
Silver Styphnate	539	7	7	0	3	2	2	21
Silver Tetrazene	540	7	7	0	3	2	2	21
Smokeless Gunpowder	541	7	7	0	3	2	2	14
Sodium Arsenate	376	0	0	0	0	2	3	5
Sodium Arsenite	377	0	0	0	0	2	3	5
Sodium Cacodylate	382	1	1	0	3	2	2	9
Sodium Chromate	386	5	0	0	0	2	3	10
Sodium Cyanide	387	7	7	3	3	2	2	24
Sodium Dichromate	379	5	0	0	0	2	3	10
Sulphur Mustard	543	7	7	3	3	1	3	24
TNT	418	7	7	0	3	0	2	19
Tear Gas (CN)	107 422	1	1	3	3	2	2	12
Tear Gas (CS)	423	1	0	3	3	2	2	11
Tetrazene	542	7	7	0	3	0	1	18
VX	288	1	1	3	3	2	3	13
Zinc Arsenate	453	0	0	0	0	0	2	2
Zinc Arsenite	454	0	0	0	0	1	2	3
Zinc Cyanide	457	7	7	3	3	1	2	23

APPENDIX B-3

WASTE TREATMENT PROCEDURES

KEY TO APPENDIX B-3

LEGEND
*E = EVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.


NAME: Bromine Pentafluoride
I.D. NO. 66
FORMULA: BrF_5
FORMULA & DESCRIPTION
T.L.*
H.I.*
INITIAL FORM:
0
25
ACCEPT. FORM: None
IDEAL FORM: Br_2
Liquid
2
21
TREATMENT PRODUCTS
NONTOXIC
EVOLVES GAS
x
EXPLOSIVE
FLAMMABLE
FORM
Gas
NAME
CF_4
TOXIC
EVOLVES GAS
x x
EXPLOSIVE
FLAMMABLE
x x
FORM
Gas
Liquid
NAME
$Br_2 + CF_4$
Br_2
T.L.*
1
2
TREATMENT
Reaction w/charcoal
Condense in ice cooled trap
Recycle
NAME
BrF_5
$Br_2 + CF_4$
Br_2
FORM OF TREATMENT PRODUCTS
HAZARD INDEX OF ORIGINAL COMPOUND
REFERS TO FORM BEFORE TREATMENT
HAZARD INDEX OF TREATMENT PRODUCT
REFERS TO MINIMUM MANDATORY TREATMENT LEVEL TO PRODUCE AN ACCEPTABLE FORM FOR UNDERGROUND STORAGE
REFERS TO BEST FORM FOR EITHER UNDERGROUND STORAGE OR CONVENTIONAL DISPOSAL
PRODUCT OF TREATMENT NONTOXIC- CONVENTIONAL DISPOSAL RECOMMENDED
PRODUCTS OF TREATMENT TOXIC - FURTHER TREATMENT DESIRABLE
TREATMENT TO BE PERFORMED
FORMULA OR DESCRIPTION OF SUBSTANCE TO BE TREATED
DECISION INDICATOR - IF WASTE IS TO BE TREATED ALL TREATMENT STEPS ABOVE LINE ARE MANDATORY; ALL THOSE BELOW ARE OPTIONAL

Pages 325 through 357 of Appendix B-3, Waste Treatment Procedures, refer to Table 7, CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS WITH NO TREATMENT. (Candidates listed in alphabetical order by name.)

Note: Wherever possible both the mandatory and optional treatment procedures have been shown. The optional treatment procedures may be most significant in treating a variety of unknown original waste forms, and might also be useful for optimizing the use of underground space through improved handling and storage.

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Aldrin

I.D. NO. 13

FORMULA: $C_{12}H_8Cl_6$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_{12}H_8Cl_6$		0	9
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ as dilute soln		1	E

NAME		$C_{12}H_8Cl_6$	
TREATMENT		Dilute: Concentrate w/activated carbon & regenerate carbon in furnace. Treat products same as below. Conc: Incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	
T.L.*		1	
TREATMENT PRODUCTS: TOXIC	NAME		
	FORM		
FLAMMABLE			
EXPLOSIVE			
EVOLVES GAS			
NONTOXIC	NAME	Ash (Possible) $NaCl + Na_2CO_3 + NaOH + H_2O$	
	FORM	Powder Dilute Soln *E	
FLAMMABLE			
EXPLOSIVE			
EVOLVES GAS			

NAME: Arsenic Trioxide

I.D. NO. 51

FORMULA: As_2O_3

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	7
ACCEPT. FORM:	As_2O_3			0	7
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid		4	1

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
As_2O_3	Treat w/hot $HNO_3 + H_2O$	1	$H_3AsO_4 + HNO_3 + N_2O_3 + H_2O$	Soln			X					
			N_2O_3	Gas			X					
$H_3AsO_4 + HNO_3 + N_2O_3 + H_2O$	Treat w/$Mg(OH)_2 + H_2O$	2	$Mg_3(AsO_4)_2 + Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Slurry								
N_2O_3	Scrub w/dilute Caustic Soln (NaOH assumed)							$NaNO_2 + NaOH + H_2O$	Dilute Soln *E			
Slurry	Filter & Wash	3	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp Solid				$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Dilute Soln *E			
$Mg_3(AsO_4)_2$	Evaporate (Optional)	4	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Insol Solid				H_2O	Vapor			X

NAME: Benzene Hexachloride (Lindane) I.D. NO. 55

FORMULA: $C_6H_6Cl_6$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	8
ACCEPT. FORM:	$C_6H_6Cl_6$		0	8
IDEAL FORM:	$NaCl + Na_2CO_3 + H_2O$ Dilute Soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_6Cl_6$	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: Incineration w/afterburner & dilute caustic scrubber (NaOH assumed)	1						$NaCl + Na_2CO_3$ $NaOH + H_2O$ Ash (possible)	Dilute Soln *E Powder			

NAME: Cacodylic Acid

FORMULA: $(CH_3)_2AsO_2H$

I.D. NO. 80

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	9
ACCEPT. FORM:	$(CH_3)_2AsO_2H$			0	9
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid		5	1

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(CH_3)_2AsO_2H$	Incineration w/afterburner & condense @ 110°C	1	As_2O_3	Solid				$CO_2 + H_2O$	Gases			X
As_2O_3	Treat w/hot HNO_3	2	$H_3AsO_4 + N_2O_3 + HNO_3 + H_2O$	Soln			X					
			N_2O_3	Gas			X					
Gas + Soln	Treat w/excess $Mg(OH)_2$	3	$Mg_3(AsO_4)_2 + Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Slurry								
Slurry	Filter & wash	4	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp Solid				$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Dilute Soln *E			
$Mg_3(AsO_4)_2 + H_2O$	Evaporate (Optional)	5	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Cadmium (as a solid) I.D. NO. 81

FORMULA: Cd

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	3
ACCEPT. FORM:	Cd		0	3
IDEAL FORM:	Cd		0	3

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: Cadmium Choride

FORMULA: $CdCl_2$

I.D. NO.83

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:				
ACCEPT. FORM:	$CdCl_2$		0	5
IDEAL FORM:	CdO		0	5
	Solid		4	2

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS: TOXIC: NAME	TOXIC: FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC: NAME	NONTOXIC: FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$CdCl_2$	Treat w/$Ca(OH)_2 + H_2O$	1	$Cd(OH)_2 + CaCl_2 + Ca(OH)_2\ H_2O$	Slurry								
$Cd(OH)_2 + CaCl_2 + Ca(OH)_2 + H_2O$	Incinerate & scrub w/ water	2	$CdO + CaCl_2 + Ca(OH)_2 + H_2O$	Slurry								
$CdO + CaCl_2 + Ca(OH)_2 + H_2O$	Filter & wash	3	$CdO + H_2O$	Damp solid			900°C X	$CaCl_2 + Ca(OH)_2 + H_2O$	Dilute Soln *E			
$CdO + H_2O$	Evaporate (Optional)	4	CdO	Solid			900°C X	H_2O	Vapor			X

NAME: Cadmium Fluoride

I.D. NO. 478

FORMULA: CdF_2

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	5
ACCEPT. FORM:	CdF_2			0	5
IDEAL FORM:	$CdO + CaF_2 + Ca(OH)_2$	Solid		2	4

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
CdF_2	Treat w/excess $Ca(OH)_2$	1	$Cd(OH)_2 + CaF_2 + Ca(OH)_2 + H_2O$	Slurry								
Slurry	Evaporate @ 320°C (Optional)	2	$CdO + CaF_2 + Ca(OH)_2$	Solid			900°C X	H_2O	Vapor			X

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NAME: Cadmium Oxide I.D. NO. 85

FORMULA: CdO

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	2
ACCEPT. FORM:	CdO		0	2
IDEAL FORM:	CdO		0	2

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

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NAME: Cadmium Phosphate **I.D. NO.** 86

FORMULA: $Cd_3(PO_4)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	2
ACCEPT. FORM:	$Cd_3(PO_4)_2$		0	2
IDEAL FORM:	$Cd_3(PO_4)_2$		0	2

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: Cadmium Sulfate　　**I.D. NO.** 481

FORMULA: $CdSO_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	5
ACCEPT. FORM:	$CdSO_4$		0	5
IDEAL FORM:	$CdO + CaSO_4 + Ca(OH)_2$ Solid		2	2

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$CdSO_4$	Treat w/$Ca(OH)_2$	1	$Cd(OH)_2 + Ca(OH)_2 + CaSO_4 + H_2O$	Slurry								
Slurry	Evaporate @ 320°C (Optional)	2	$CdO + Ca(OH)_2 + CdSO_4$	Solid		900°C	X	H_2O	Vapor			X

NAME: Calcium Arsenate

I.D. NO. 87

FORMULA: $Ca_3(AsO_4)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	3
ACCEPT. FORM:	$Ca_3(AsO_4)_2$		0	3
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$		3	1

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$Ca_3(AsO_4)_2$	Treat w/$Mg(OH)_2$	1	$Mg_3(AsO_4)_2 + Ca(OH)_2 + Mg(OH)_2 + H_2O$	Slurry								
Slurry	Filter & wash	2	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp Solid				$Ca(OH)_2 + Mg(OH)_2 + H_2O$	Dilute Soln *E			
$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Evaporate (Optional)	3	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

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NAME: Calcium Arsenite

I.D. NO. 88

FORMULA: $CaAsO_3H$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:				
ACCEPT. FORM:	$CaAsO_3H$		0	4
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$ Solid		4	1

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$CaAsO_3H$	Oxidize with hot HNO_3	1	$Ca_3(AsO_4)_2 + N_2O_3 + HNO_3 + H_3AsO_4 + H_2O$	Slurry			X					
			N_2O_3	Gas			X					
Slurry	Treat with $Mg(OH)_2$	2	$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Slurry								
N_2O_3	Dilute alkaline scrubber (NaOH assumed)	2						$NaOH + NaNO_2 + H_2O$	Dilute soln *E			
Slurry	Filter & wash	3	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Dilute soln *E			
Damp solid	Evaporate (Optional)	4	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Copper Acetoarsenite

I.D. NO. 490

FORMULA: $(C_2H_3O_2)_2Cu \cdot 3Cu(AsO_2)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:					
ACCEPT. FORM:	$(C_2H_3O_2)_2Cu \cdot 3Cu(AsO_2)_2$			0	9
IDEAL FORM:	$CuO + Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid		4	1

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TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_2H_3O_2)_2Cu.3Cu(AsO_2)_2$	Incineration w/afterburner & scrub w/HNO_3 (hot)	1	$N_2O_3 + CO_2$ $Cu(NO_3)_2 + HNO_3 + N_2O_3 + CO_2 + H_3AsO_4 + H_2O$	Gas Soln			x X					X
$Cu(NO_3)_2 + H_3AsO_4 + HNO_3 + H_2O + N_2O_3 + CO_2$	Treat w/$Mg(OH)_2$	2	$Cu(OH)_2 + CuO + Mg_3(AsO_4) + Mg(NO_3)_2 + Mg(NO_2)_2 + MgCO_3 + Mg(OH)_2 + H_2O$	Slurry								
Slurry	Filter & wash	3	$Cu(OH)_2 + CuO + Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp Solid				$Mg(NO_3)_2 + Mg(NO_2)_2 + MgCO_3 + Mg(OH)_2 + H_2O$	Dilute Soln *E			
$Cu(OH)_2 + CuO + Mg(OH)_2 + Mg_3(AsO_4)_2 + H_2O$	Evaporate w/heat (Optional)	4	$CuO + Mg(OH)_2 + Mg_3(AsO_4)_2$	Solid				H_2O	Vapor			X

NAME: Copper Arsenate

I.D. NO.119

FORMULA: $Cu_3(AsO_4)H_2O$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:				
ACCEPT. FORM:	$Cu_3(AsO_4)H_2O$		0	2
IDEAL FORM:	$Cu_3(AsO_4)H_2O$		0	2

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TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: 2,4-D I.D. NO. 135

FORMULA: $C_8H_6Cl_2O_3$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	8
ACCEPT. FORM:	$C_8H_6Cl_2O_3$		0	8
IDEAL FORM:	$NaCl + Na_2CO_3 + H_2O + NaOH$ Dilute soln		1	E

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TREATMENT PRODUCTS

NAME		$C_8H_6Cl_2O_3$	
TREATMENT		Dilute: concentrate w/activated carbon beds w/carbon regeneration in furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute alkaline soln (NaOH assumed)	
T.L.*		1	
TOXIC	NAME		
	FORM		
FLAMMABLE			
EXPLOSIVE			
EVOLVES GAS			
NONTOXIC	NAME	$NaCl + Na_2CO_3 +$ $NaOH + H_2O$ Ash (possible)	
	FORM	Dilute soln *E Powder	
FLAMMABLE			
EXPLOSIVE			
EVOLVES GAS			

NAME: DDD

I.D. NO. 136

FORMULA: $(ClC_6H_4)_2\ C_2H_2Cl_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	9
ACCEPT. FORM:	$(ClC_6H_4)_2\ C_2H_2Cl_2$			0	9
IDEAL FORM:	$NaCl+Na_2CO_3+NaOH+H_2O$	Dilute soln		1	E

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			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
$(ClC_6H_4)_2C_2H_2Cl_2$	Dilute: Concentration with activated carbon w/regeneration of carbon in furnace. Treat products same as below. Conc: Incineration w/afterburner & scrubbing w/dilute alkaline solution (NaOH assumed)	1						$NaCl + Na_2CO_3 +$ $NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

NAME: DDT **I.D. NO.** 137

FORMULA: $(ClC_6H_4)_2C_2HCl_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	9
ACCEPT. FORM:	$(ClC_6H_4)_2C_2HCl_3$			0	9
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$	Dilute soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
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TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E Powder	
	NAME	$NaCl + Na_2CO_3 + NaOH + H_2O$ Ash (possible)	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	

NAME	TREATMENT	
$(ClC_6H_4)_2C_2HCl_3$	Dilute: concentrate w/activated carbon w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute alkaline soln (NaOH assumed)	

NAME: Demeton

I.D. NO. 491

FORMULA: $C_8H_{19}O_3PS_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_8H_{19}O_3PS_2$		0	9
IDEAL FORM:	$Na_2CO_3 + Na_3PO_4 + Na_2SO_3 + NaOH + H_2O$ Dilute soln		1	E

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ALL OTHER LEVELS INCLUDE
CONTAINERS.

			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
$C_8H_{19}O_3PS_2$	Dil: concentration w/activated carbon beds w/carbon regeneration in furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute alkaline soln (NaOH assumed)	1						$Na_2CO_3 + Na_3PO_4 + Na_2SO_3 + NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

NAME: Dieldrin

I.D. NO. 149

FORMULA: $C_{12}H_8OCl_6$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_{12}H_8OCl_6$		0	9
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_{12}H_{10}OCl_6$	Dilute: concentrate w/activated carbon beds w/carbon regeneration in furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	1						$NaCl + Na_2CO_3 + NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

NAME: Endrin I.D. NO. 170

FORMULA: $C_{12}H_8Cl_6O$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_{12}H_8Cl_6O$		0	9
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$C_{12}H_8Cl_6O$	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/after-burner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaCl + Na_2CO_3$ $+ NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

NAME: Guthion **I.D. NO.** 495

FORMULA: $C_{10}H_{12}N_3O_3PS_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_{10}H_{12}N_3O_3PS_2$		0	9
IDEAL FORM:	$NaNO_x + Na_2CO_3 + Na_3PO_4 + Na_2SO_3 + NaOH + H_2O$ Dilute soln		1	E

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$C_{10}H_{12}N_3O_3PS_2$	Dilute: conc w/activated carbon beds w/carbon regenerated in furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	1						$Na_2CO_3 + Na_3PO_4 + Na_2SO_3 + NaNO_x + NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

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*H.I. = HAZARD INDEX
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T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Heptachlor

I.D. NO. 496

FORMULA: $C_{10}H_5Cl_7$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_{10}H_5Cl_7$		0	9
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_{10}H_5Cl_7$	Dilute: concentrate w/activated carbon w/carbon regenerated in a furnace. Treat products same as below. Conc: incineration w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	1						$NaCl + Na_2CO_3$ $+ NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

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T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME. Lead Arsenate

I.D. NO. 235

FORMULA: $PbHAsO_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	4
ACCEPT. FORM:	$PbHAsO_4$		0	4
IDEAL FORM:	$PbHAsO_4$		0	4

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: Lead Arsenite **I.D. NO.** 236

FORMULA: $Pb(AsO_2)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	3
ACCEPT. FORM:	$Pb(AsO_2)_2$		0	3
IDEAL FORM:	$Pb(AsO_2)_2$		0	3

TREATMENT PRODUCTS			
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	NONTOXIC	FORM	
		NAME	
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	TOXIC	FORM	
		NAME	
	T.L.*		

TREATMENT	No Treatment Necessary
NAME	

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NAME: Magnesium Arsenite I.D. NO. 245

FORMULA: $Mg_3(AsO_3)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	4
ACCEPT. FORM:	$Mg_3(AsO_3)_2$		0	4
IDEAL FORM:	$Mg_3(AsO_4)_2$ Solid		3	1

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Mg_3(AsO_3)_2$	Treat w/hot HNO_3	1	$Mg_3(AsO_4)_2$ + N_2O_3 + H_2O + HNO_3	Slurry			X					
			N_2O_3	Gas			X					
Slurry	Filter & wash & neutralize filtrate	2	$Mg_3(AsO_4)_2$ + H_2O	Damp solid				$NaNO_2$ + $NaNO_3$ + $NaOH$ + H_2O	Dilute soln *E			
N_2O_3	Scrub w/dilute caustic soln (NaOH) assumed	2						$NaNO_2$ + $NaOH$ + H_2O	Dilute soln *E			
$Mg_3(AsO_4)_2$ + H_2O(Damp solid)	Evaporate (Optional)	3	$Mg_3(AsO_4)_2$	Solid				H_2O	Vapor			X

NAME: Manganese Arsenate **I.D. NO.** 500

FORMULA: $MnHAsO_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	3
ACCEPT. FORM:	$MnHAsO_4$		0	3
IDEAL FORM:	$MnHAsO_4$		0	3

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: Pentachlorophenol **I.D. NO.** 322

FORMULA: Cl_5C_6OH

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	7
ACCEPT. FORM:	Cl_5C_6OH		0	7
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
Cl_5C_6OH	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaCl + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			

NAME: Potassium Arsenite

I.D. NO. 341

FORMULA: $KAsO_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	5
ACCEPT. FORM:	$KAsO_2$		0	5
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$		4	1

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$KAsO_2$	Treat w/hot HNO_3	1	$K_3AsO_4 + N_2O_3 +$ $HNO_3 + H_2O$	Soln			X					
			N_2O_3	Gas			X					
Soln + gas	Treat w/$Mg(OH)_2$	2	$Mg_3(AsO_4)_2 +$ $Mg(NO_2)_2 +$ $Mg(NO_3)_2 +$ $Mg(OH)_2 + KOH +$ $KNO_3 + KNO_2 + H_2O$	Slurry								
Slurry	Filter & wash	3	$Mg_3(AsO_4)_2 +$ $Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_2)_2 +$ $Mg(NO_3)_2 +$ $Mg(OH)_2 + KOH +$ $KNO_3 + KNO_2 +$ H_2O	Dilute soln *E			
Damp solid	Evaporate (Optional)	4	$Mg_3(AsO_4)_2$ $Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Sodium Arsenate

I.D. NO. 376

FORMULA: Na_2HAsO_4

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	5
ACCEPT. FORM:	Na_2HAsO_4		0	5
IDEAL FORM:	$Mg_3(AsO_4)_2$ + $Mg(OH)_2$ Solid		3	1

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
Na_2HAsO_4	Treat w/$Mg(OH)_2$	1	$Mg_3(AsO_4)_2$ + $Mg(OH)_2$ + $NaOH$ + H_2O	Slurry								
Slurry	Filter & wash	2	$Mg_3(AsO_4)_2$ + $Mg(OH)_2$ + H_2O	Damp solid				$NaOH$ + $Mg(OH)_2$ + H_2O	Dilute soln *E			
$Mg_3(AsO_4)_2$ + H_2O	Evaporate (Optional)	3	$Mg_3(AsO_4)_2$ + $Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Sodium Arsenite

I.D. NO. 377

FORMULA: Na_3AsO_3 & $NaAsO_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:				
ACCEPT. FORM:	Na_3AsO_3 or $NaAsO_2$		0	5
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$. Solid		4	1

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			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
Na_3AsO_3	Treat w/hot HNO_3	1	$Na_3AsO_4 + N_2O_3 + HNO_3 + H_2O$	Soln			X					
			N_2O_3	Gas			X					
Soln + Gas	Treat w/$Mg(OH)_2$	2	$Mg_3(AsO_4)_2 + Mg(NO_2)_2 + Mg(NO_3)_2$ $Mg(OH)_2 + NaOH + NaNO_3 + NaNO_2 + H_2O$	Slurry								
Slurry	Filter & wash	3	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + NaOH + NaNO_3 + NaNO_2 + H_2O$	Dilute soln *E			
$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Evaporate (Optional)	4	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Sodium Cacodylate **I.D. NO.** 382

FORMULA: $C_2H_6O_2AsNa$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	9
ACCEPT. FORM:	$C_2H_6O_2AsNa$		0	9
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$ Solid		5	1

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TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_2H_6O_2AsNa$	Incineration at 1000° c w/ afterburner & precipitator, condense @ 120°c	1	Na_2O As_2O_3	Crystals Powder			 X	$CO_2 + H_2O$	Gas			X
Na_2O (from precipitator)	Dilute w/H_2O	2						$NaOH + H_2O$	Soln (recycle)			
As_2O_3 (from condensor)	Treat w/hot HNO_3	2	$H_3AsO_4 + HNO_3 + N_2O_3 + H_2O$ N_2O_3	Soln Gas			X X					
$H_3AsO_4 + HNO_3 + N_2O_3 + H_2O$	Treat w/$Mg(OH)_2 + H_2O$	3	$Mg_3(AsO_4)_2 + Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Slurry								
N_2O_3	Scrub w/dilute caustic soln (NaOH assumed)	3						$NaNO_2 + NaOH + H_2O$	Dilute soln *E			
Slurry	Filter & wash	4	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Dilute soln *E			
Damp solid	Evaporate (Optional)	5	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Zinc Arsenate I.D. NO. 451

FORMULA: $Zn_3(AsO_4)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	2
ACCEPT. FORM:	$Zn_3(AsO_4)_2$		0	2
IDEAL FORM:	$Zn_3(AsO_4)_2$		0	2

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ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	No Treatment Necessary
NAME	

NAME: Zinc Arsenite I.D. NO. 454

FORMULA: $Zn(AsO_2)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	3
ACCEPT. FORM:	$Zn(AsO_2)_2$		0	3
IDEAL FORM:	$Zn_3(AsO_4)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2$ Solid		4	2

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			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
FORM	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Zn(AsO_2)_2$	Treat w/hot $HNO_3 + H_2O$	1	$Zn_3(AsO_4)_2 + N_2O_3 + HNO_3 + H_3AsO_4 + H_2O$	Slurry			x					
			N_2O_3	Gas			x					
Slurry	Treat w/$Mg(OH)_2$	1	$Zn_3(AsO_4)_2 + Mg(NO_3)_2 + Mg(NO_2)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Slurry								
N_2O_3	Dilute caustic scrubber (NaOH assumed)	2						$NaNO_2 + NaOH + H_2O$	Dilute soln **			
Slurry	Filter & wash	3	$Zn_3(AsO_4)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_3)_2 + Mg(NO_2)_2 + Mg(OH)_2 + H_2O$	Dilute soln **			
Damp solid	Evaporate (Optional)	4	$Zn_3(AsO_4)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			x

Pages 359 through 404 of Appendix B-3, Waste Treatment Procedures, refer to Table 8, CANDIDATE WASTES WHICH ARE ACCEPTABLE FOR UNDERGROUND STORAGE IN CONTAINERS AFTER TREATMENT. (Candidates listed in alphabetical order by name.)

NAME: Ammonium Chromate

I.D. NO. 21

FORMULA: $(NH_4)_2CrO_4$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	18
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Sludge		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(NH_4)_2CrO_4$	Reduction w/SO_2	1	$(NH_4)_2SO_3 + Cr_2(SO_4)_3 + SO_2 + H_2O$	Slurry			X					
Slurry	Precipitation by adjusting pH ≥ 9.5 (NaOH assumed)	2	$Cr(OH)_3$ $(NH_4)_2SO_3 + NH_4OH + Na_2SO_4 + (NH_4)_2SO_4 + NaOH + Na_2SO_3 + H_2O$	Precipitate Soln			 X					
Soln + precipitate	Filter	3	$Cr(OH)_3 + H_2O$	Sludge				$(NH_4)_2SO_3 + NH_4OH + Na_2SO_4 + (NH_4)_2SO_4 + NaOH + Na_2SO_3 + H_2O$	Dilute soln *E			X
$Cr(OH)_3 + H_2O$	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			X

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NAME: Ammonium Dichromate I.D. NO. 22

FORMULA: $(NH_4)_2Cr_2O_7$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	18
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Sludge		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(NH_4)_2Cr_2O_7$	Reduction w/SO_2	1	$(NH_4)_2SO_3 + Cr_2(SO_4)_3 + SO_2 + H_2O$	Slurry			X					
Slurry	Precipitation by adjusting PH ≥ 9.5 (NaOH assumed)	2	$Cr(OH)_3$	Precipitate								
			$(NH_4)_2SO_3 + NH_4OH + Na_2SO_4 + (NH_4)_2SO_4 + NaOH + Na_2SO_3 + H_2O$	Soln			X					
Soln + precipitate	Filter & wash	3	$Cr(OH)_3 + H_2O$	Sludge				$(NH_4)_2SO_3 + NH_4OH + Na_2SO_4 + (NH_4)_2SO_4 + NaOH + Na_2SO_3 + H_2O$	Dilute soln *E			
$Cr(OH)_3 + H_2O$	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			X

NAME: Ammonium Picrate, Dry & Wet

I.D. NO. 27, 28

FORMULA: $NH_4C_6H_2N_3O_7$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$NH_4C_6H_2N_3O_7$	Controlled incineration w/ afterburner & precipitator & condense (20°C)	1	PbO + metal oxides	Solid				$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
	Scrub gases w/dilute caustic soln (NaOH assumed)		Hg + H_2O	Liquid			x					
Hg + H_2O	Purify & recycle	2										

NAME: Antimony Pentafluoride **I.D. NO.** 36

FORMULA: SbF_5

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	11
ACCEPT. FORM:	$CaF_2+CaCl_2+Ca(OH)_2+H_2O$ Slurry; Sb Solid		4; 3	2
IDEAL FORM:	CaF_2+CaCl_2; Sb Solids		5; 4	2

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
SbF_5	Dissolve in dilute HCl & saturate w/H_2S	1	$Sb_2S_x + HCl + HF + H_2S + H_2O$	Slurry	X	X	X					
Slurry	Filter & wash	2	$Sb_2S_x + H_2O$	Precipitate	X	X						
			$HCl + HF + H_2S + H_2O$	Soln	X	X	X					
Soln	Air strip H_2S	3	$H_2S + H_2O$	Gas	X	X	X					
			$HCl + HF + H_2O$	Soln	X	X	X					
$Sb_2S_x + H_2O$	Roast w/carbon	3	Sb	Solid			X					
			$SO_2 + CO_2 + H_2O$	Gas			X					
$H_2S + H_2O$ & $SO_2 + CO_2 + H_2O$	Incinerate & scrub w/dilute caustic (NaOH assumed)	4						$Na_2SO_3 + Na_2CO_3$ $NaOH + H_2O$	Dilute soln *E			
$HCl + HF + H_2O$	Treat w/lime ($Ca(OH_2)$)	4	$CaF_2 + CaCl_2 + H_2O + Ca(OH)_2$	Slurry								
Sb	Recycle or store	4	Sb	Solid			X					
$CaF_2 + CaCl_2$ $Ca(OH)_2 + H_2O$	Evaporate (Optional)	5	$CaF_2 + CaCl_2 + Ca(OH)_2$	Solid	1,380°C			H_2O	Vapor			X

NAME: Antimony Trifluoride I.D. NO. 43

FORMULA: SbF_3

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	11
ACCEPT. FORM:	$CaF_2+CaCl_2+Ca(OH)_2+H_2O$ Slurry; Sb Solid			4; 3	2
IDEAL FORM:	$CaF_2 + CaCl_2$; Sb	Solids		5; 4	2

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
SbF_3	Dissolve in dilute HCl & saturate w/H_2S	1	$Sb_2S_x + HCl + HF + H_2S + H_2O$	Slurry	X	X	X					
Slurry	Filter & wash	2	$Sb_2S_x + H_2O$	Precipitate	X	X						
			$HCl + HF + H_2S + H_2O$	Soln	X	X	X					
Soln	Air strip of H_2S	3	$H_2S + H_2O$	Gas	X	X	X					
			$HCl + HF + H_2O$	Soln	X	X	X					
$Sb_2S_x + H_2O$	Roast w/carbon	3	Sb	Solid			X					
			$SO_2 + CO_2 + H_2O$	Gas			X					
$H_2S + H_2O$ & $SO_2 + CO_2 + H_2O$	Incinerate & scrub w/dilute caustic (NaOH assumed)	4						$Na_2SO_3 + Na_2CO_3$ NaOH + H_2O	Dilute soln *E			
$HCl + HF + H_2O$	Treat w/lime ($Ca(OH)_2$)	4	$CaF_2 + CaCl_2 + H_2O + Ca(OH)_2$	Slurry								
Sb	Recycle or store	4	Sb	Solid			X 1,380°C					
$CaF_2 + CaCl_2 + Ca(OH)_2 + H_2O$	Evaporate (Optional)	5	$CaF_2 + CaCl_2 + Ca(OH)_2$	Solid				H_2O	Vapor			X

NAME:	Arsenic Trichloride	**I.D. NO.**	50
FORMULA:	$AsCl_3$		

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	11
ACCEPT. FORM:	$Ca_3(AsO_3)_2 + CaCl_2 + Ca(OH)_2 + H_2O$	Soln		1	5
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid		4-A	1

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			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$AsCl_3$	Treat w/excess $Ca(OH)_2$	1	$Ca_3(AsO_3)_2 + CaCl_2 + Ca(OH)_2 + H_2O$	Soln								
$Ca_3(AsO_3)_2 + CaCl_2 + Ca(OH)_2 + H_2O$	Evaporate	2	$Ca_3(AsO_3)_2 + CaCl_2 + Ca(OH)_2$	Very soluble Granular Solid				H_2O	Vapor			X
Alternate $AsCl_3$	Treat w/hot $HNO_3 + H_2O$	1	$H_3AsO_4 + HCl + HNO_3 + N_2O_3 + H_2O$ $HCl + N_2O_3$	Soln Gases			X X					
$H_3AsO_4 + HCl + HNO_3 + N_2O_3 + H_2O$	Treat w/excess $Mg(OH)_2+H_2O$	2	$Mg_3(AsO_4)_2 + MgCl_2 + Mg(NO_2)_2 + Mg(NO_3)_2 + Mg(OH)_2 + H_2O$	Slurry								
$HCl + N_2O_3$ (gases)	Scrub w/dilute caustic soln (NaOH assumed)							$NaCl + NaNO_2$ $NaOH + H_2O$	Dilute soln *E			
Slurry	Filter & wash	3	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$MgCl_2+Mg(NO_3)_2+Mg(NO_2)_2+Mg(OH)_2 + H_2O$	Dilute soln *E			
$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Evaporate (Optional)	4	$Mg_3(AsO_4)_2 + Mg(OH)_2$	Solid				H_2O	Vapor			X

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NAME: Cadmium, Powdered **I.D. NO.** 82

FORMULA: Cd

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	18
ACCEPT. FORM:	Cd	Solid		1	3
IDEAL FORM:	Cd	Solid		1	3

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM		
	NAME		
EVOLVES GAS		x	
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM	Solid	
	NAME	Cd	
T.L.*		1	
	TREATMENT	Melt & cast into solid	Store or recycle
	NAME		

NAME: Cadmium Cyanide I.D. NO. 84

FORMULA: $Cd(CN)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	$CdO + H_2O$	Damp solid		3	2
IDEAL FORM:	CdO	solid		4	2

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			TREATMENT PRODUCTS								
			TOXIC					NONTOXIC			
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Cd(CN)_2$	Conc: Dilute· Dilute: Oxidation w/hypochlorite ion ($Ca(OCl)_2$ assumed)	1	$Cd(OH)_2 + CaCl_2 + Ca(OCl)_2 + CdCO_3 + N_2 + H_2O$	Slurry			X	$CO_2 + N_2$	Gases			X
Slurry	Evaporate @ 500°C	2	$CdO + CaCl_2 + Ca(OH)_2$	Solid				$CO_2 + N_2 + O_2 + H_2O$	Gas			X
$CdO + CaCl_2 + Ca(OH)_2$	Wash & filter	3	$CdO + H_2O$	Damp solid			X 900°C	$CaCl_2 + Ca(OH)_2 + H_2O$	Dilute soln *E			
$CdO + H_2O$	Evaporate (Optional)	4	CdO	Solid			X 900°C	H_2O	Vapor			X

NAME: Cadmium Nitrate **I.D. NO.** 479

FORMULA: $Cd(NO_3)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	17
ACCEPT. FORM:	$CdO + H_2O$	Damp solid		3	2
IDEAL FORM:	CdO	solid		4	2

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Cd(NO_3)_2$	Conc: & dilute : Treat w/excess $Ca(OH)_2$	1	$Cd(OH)_2 + Ca(NO_3)_2 + Ca(OH)_2 + H_2O$	Slurry								
Slurry	Evaporate @ 320°C	2	$CdO + Ca(NO_3)_2 + Ca(OH)_2$	Solid			X 900°C	H_2O	Vapor			X
$CdO + Ca(NO_3)_2 + Ca(OH)_2$	Wash & filter	3	$CdO + H_2O$	Damp solid			X 900°C	$Ca(NO_3)_2 + Ca(OH)_2 + H_2O$	Dilute soln *E			
$CdO + H_2O$	Evaporate (Optional)	4	CdO	Solid			X 900°C	H_2O	Vapor			X

NAME: Cadmium Potassium Cyanide

FORMULA: $Cd(CN)_2 \cdot 2KCN$

I.D. NO. 480

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	$CdO + H_2O$	Damp solid		3	2
IDEAL FORM:	CdO	solid		4	2

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Cd(CN)_2 \cdot 2KCN$	Oxidize with hypochlorite ion ($Ca(OCl)_2$ assumed)	1	$Cd(OH)_2 + KOH + CaCl_2 + Ca(OCl)_2 + CdCO_3 + K_2CO_3 + N_2 + H_2O$	Slurry			x	$CO_2 + N_2$	Gas			x
Slurry	Evaporate @ 500°C	2	$CdO + CaCl_2 + KOH + Ca(OH)_2$	Solid				$CO_2 + N_2 + O_2 + H_2O$	Gas			x
$CdO + CaCl_2 + KOH + Ca(OH)_2$	Wash & filter	3	$CdO + H_2O$	Damp solid			x 900°C	$CaCl_2 + KOH + Ca(OH)_2 + H_2O$	Dilute soln *E			
$CdO + H_2O$	Evaporate (optional)	4	CdO	Solid			x 900°C	H_2O	Vapor			x

NAME: Chromic Acid (liquids, chromium trioxide) **I.D. NO.** 114

FORMULA: CrO_3

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	15
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Damp solid		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

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			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
CrO_3	Reduction w/SO_2	1	$Cr_2(SO_4)_3 + SO_2 + H_2O$	Slurry			x					
$Cr_2(SO_4)_3 + SO_2 + H_2O$	Precipitation by adjusting pH to 8.5 (NaOH assumed)	2	$Cr(OH)_3 + Na_2SO_3 + Na_2SO_4 + NaOH + H_2O$	Slurry								
Slurry	Filter & dilute filtrate	3	$Cr(OH)_3 + H_2O$	Damp solid				$Na_2SO_3 + Na_2SO_4 + NaOH + H_2O$	Dilute soln *E			
$Cr(OH)_3 + H_2O$	Evaporate (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			x

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NAME: Copper Acetylide **I.D. NO.** 517

FORMULA: Cu_2C_2

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	19
ACCEPT. FORM:	$CuO + CuCO_3$ Solid		1	1
IDEAL FORM:	$CuO + CuCO_3$ Solid		1	1

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS: TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
Cu_2C_2	Detonation	1	$CuO + CuCO_3$	Solid								

NAME: Copper Chlorotetrazole **I.D. NO.** 518

FORMULA: Not available

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	20
ACCEPT. FORM:	CuO	Solid		1	1
IDEAL FORM:	CuO	Solid		1	1

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ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x$ + Na_2CO_3 + $NaOH$ + $NaCl$ + H_2O	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM	Solid	
	NAME	CuO	
T.L.*		1	
	TREATMENT	Controlled incineration w/ afterburner & precipitator, scrub gases with/dilute alkaline soln (NaOH assumed)	
	NAME	Copper Chlorotetrazole	

NAME: Copper Cyanide

FORMULA: $Cu(CN)_2$

I.D. NO.120

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	22
ACCEPT. FORM:	Decomposes @ ambient temp and press			
IDEAL FORM:	CuO		3	1

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			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Cu(CN)_2$	Oxidation w/hypochlorite ion (NaOCl assumed)	1	$Cu(OH)_2 + CuCO_3 + NaCl + NaOCl + H_2O + N_2$	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Filter & wash	2	$Cu(OH)_2 + CuCO_3 + H_2O$	Damp solid				$NaCl + NaOCl + N_2 + H_2O$	Dilute soln *E			X
$CuO + CuCO_3 + H_2O$	Evaporate with heat (Optional)	3	CuO	Solid				$H_2O + CO_2$	Gas			X

NAME: Cuprous (copper) Cyanide **I.D. NO.** 128

FORMULA: CuCN

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	22
ACCEPT. FORM:	$Cu(OH)_2 + CuCO_3 + H_2O$	Damp solid		2	1
IDEAL FORM:	CuO	solid		3	1

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
CuCN	Oxidation w/hypochlorite ion (NaOCl assumed)	1	$Cu(OH)_2 + CuCO_3 + N_2 + NaCl + NaOCl + H_2O$	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Filter & wash	2	$Cu(OH)_2 + CuCO_3 + H_2O$	Damp solid				$NaCl + NaOCl + N_2 + H_2O$	Dilute soln *E			X
$Cu(OH)_2 + CuCO_3 + H_2O$	Evaporate w/heat (Optional)	3	CuO	Solid				$H_2O + CO_2$	Gas			X

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NAME: Cyanides I.D. NO. 129

FORMULA: (Variable)

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Heavy metal hydroxides or carbonates + H_2O	Damp solid		2	1
IDEAL FORM:	Heavy metal oxides or carbonates	Solid		3	1

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
Cyanides	Oxidation w/hypochlorite ion (NaOCl assumed)	1	Heavy metals as CO_3 or OH + N_2 + NaCl + NaOCl + H_2O	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Filter & wash	2	Heavy metals as OH or CO_3 + H_2O	Damp solid				N_2 + NaCl + NaOCl + H_2O	Dilute soln *E			X
Damp solid	Evaporate (Optional)	3	Heavy metal oxides or carbonates	Solid				$H_2O + CO_2$	Vapor			X

NAME: Detonators & Primers I.D. NO. 520

FORMULA: (Variable)

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	17
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
520	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides Hg + H_2O	Solid Liquid			x	$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
Hg + H_2O	Purify & recycle	2										

NAME: Diazodinitrophenol (DDNP) **I.D. NO.** 521

FORMULA: $C_6H_2O_5N_4$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	20
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_2O_5N_4$	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

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NAME: Dinitrotoluene (DNT) I.D. NO. 165

FORMULA: $(NO_2)_2C_6H_3CH_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solids		1	3
IDEAL FORM:	Metal oxides + PbO	Solids		1	3

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TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(NO_2)_2C_6H_3CH_3$	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides Hg + H_2O	Solid Liquid			 x	$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
Hg + H_2O	Purify & recycle	2										

NAME: Dipentaerythritol Hexanitrate (DPEHN) **I.D. NO.** 522

FORMULA: $C_{10}H_{16}N_6O_{19}$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	20
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_{10}H_{16}N_6O_{19}$	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			 X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME: Fluorine **I.D. NO.** 200

FORMULA: F_2

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	19
ACCEPT. FORM:	$CaF_2+CaSiO_3+Ca(OH)_2+H_2O$	Slurry		2	3
IDEAL FORM:	$CaF_2+CaSiO_3+Ca(OH)_2$	Solid		3	2

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TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
F_2 (SiF_4 and/or HF possible contaminants)	Reaction w/charcoal	1	HF + SiF_4 (possibly) + CF_4	Gas			X					
HF + SiF_4 + CF_4	Scrub w/$Ca(OH)_2$	2	CaF_2 + $CaSiO_3$ + $Ca(OH)_2$ + H_2O	Slurry				CF_4	Gas			X
Slurry	Evaporate (Optional)	3	CaF_2 + $CaSiO_3$ + $Ca(OH)_2$	Solid				H_2O	Vapor			X

NAME: GB (Nonpersistent nerve gas) **I.D. NO.** 287

FORMULA: $C_4H_{10}O_2PF$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	$CaF_2+Ca_2P_2O_7+CaCO_3+Ca(OH)_2+H_2O$	Slurry		1	3
IDEAL FORM:	$CaF_2+Ca_2P_2O_7+CaCO_3+Ca(OH)_2$	Solid		2	2

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	T.L.*	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$C_4H_{10}O_2PF$	Incineration w/afterburner & scrub w/caustic soln ($Ca(OH)_2$ assumed)	1	$CaF_2 + Ca_2P_2O_7 + CaCO_3 + Ca(OH)_2 + H_2O$	Slurry								
Slurry	Evaporation (Optional)	2	$CaF_2 + Ca_2P_2O_7 + CaCO_3 + Ca(OH)_2$	Solid				H_2O	Vapor			X

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NAME: Gelatinized Nitrocellulose (PNC) **I.D. NO.** 523

FORMULA: $C_{12}H_{17}(ONO_2)_3O_7$ to $C_{12}H_{14}(ONO_2)_6O_4$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	18
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
PNC	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			 x	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME: Lead Azide I.D. NO. 529

FORMULA: $Pb(N_3)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	21
ACCEPT. FORM:	Pb	Solid		1	1
IDEAL FORM:	Pb	Solid		1	1

NAME			$Pb(N_3)_2$	Pb
TREATMENT			Electrolytic destruction	Recycle or store (Optional)
T.L.*			1	2
TREATMENT PRODUCTS	TOXIC	NAME	Pb	
		FORM	Solid	
	FLAMMABLE			
	EXPLOSIVE			
	EVOLVES GAS			
	NONTOXIC	NAME	N_2	
		FORM	Gas	
	FLAMMABLE			
	EXPLOSIVE			
	EVOLVES GAS		X	

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NAME: Lead Azide **I.D. NO.** 529

FORMULA: $Pb(N_3)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$Pb(N_3)_2$	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			 X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME:	Lead Cyanide		**I.D. NO.** 239	
FORMULA:	$Pb(CN)_2$			
	FORMULA & DESCRIPTION		**T.L.***	**H.I.***
INITIAL FORM:			0	23
ACCEPT. FORM:	$PbO + H_2O$	Damp Solid	2	3
IDEAL FORM:	PbO	Solid	4	3

TREATMENT PRODUCTS

NAME	**TREATMENT**	**T.L.***	**TOXIC NAME**	**TOXIC FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NONTOXIC NAME**	**NONTOXIC FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$Pb(CN)_2$	Oxidation w/hypochlorite ion (NaOCl assumed)	1	$Pb(OH)_2 + NaCl + PbCO_3 + NaOCl + H_2O + N_2$	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Evaporate w/heat (315°C)	2	$PbO + NaCl$	Solid				$N_2 + O_2 + H_2O + CO_2$	Gas			X
$PbO + NaCl$	Dilute, filter & dilute filtrate	3	$PbO + H_2O$	Damp solid				$NaCl + H_2O$	Dilute soln *E			
$PbO + H_2O$	Evaporate (Optional)	4	PbO	Solid				H_2O	Vapor			X

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ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME: Lead 2, 4 Dinitroresorcinate (LDNR) I.D. NO. 530

FORMULA: $C_6H_2O_6N_2Pb$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	19
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_2O_6N_2Pb$	Controlled incineration w/ afterburner & precipitator & condense (20°C). Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides	Solid				$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
Hg + H_2O	Purify & recycle		Hg + H_2O	Liquid			X					

NAME: Lead 2, 4 Dinitroresorcinate (LDNR) **I.D. NO.** 530

FORMULA: $C_6H_2O_6N_2Pb$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	19
ACCEPT. FORM:	PbO Solid		1	3
IDEAL FORM:	PbO Solid		1	3

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_2O_6N_2Pb$	Controlled incineration w/ afterburner & precipitator, scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO	Solid				$NaNO_x + Na_2CO_3 +$ $NaOH + H_2O$	Dilute soln *E			

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Lead Styphnate

I.D. NO. 531

FORMULA: $C_6H(NO_2)_3(O_2Pb)$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	20
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H(NO_2)_3(O_2Pb)$	Controlled incineration w/ afterburner & precipitator. Condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			 X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *F			
$Hg + H_2O$	Purify & recycle	2										

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Lead Styphnate **I.D. NO.** 531

FORMULA: $C_6H(NO_2)_3(O_2Pb)$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	20
ACCEPT. FORM:	PbO	Solid		1	3
IDEAL FORM:	PbO	Solid		1	3

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H(NO_2)_3(O_2Pb)$	Controlled incineration w/ afterburner & precipitator. Scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO	Solid				$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			

NAME: Lewisite

I.D. NO. 243

FORMULA: $C_2H_2AsCl_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	11
ACCEPT. FORM:	$CaCl_2+Ca_3(AsO_3)_2+Ca(OH)_2+H_2O$	Soln		1	5
IDEAL FORM:	$Mg_3(AsO_4)_2 + Mg(OH)_2$	solid		5	1

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_2H_2AsCl_3$	Conc: & dilute: Controlled incineration w/ afterburner w/caustic scrubber ($Ca(OH)_2$ assumed)	1	$CaCl_2 + Ca_3(AsO_3)_2 + Ca(OH)_2 + H_2O$	Soln								
Soln	Evaporate (Optional)	2	$CaCl_2 + Ca_3(AsO_3)_2 + Ca(OH)_2$	Crystal-line solid				H_2O	Vapor			X
Alternate $C_2H_2AsCl_3$	Controlled incineration w/ afterburner	1	$HCl + As_2O_3 + CO_2 + H_2O$	Gas			X					
Gas	Treat w/hot HNO_3 soln	2	$HCl + H_3AsO_4 + N_2O_3 + CO_2 + HNO_3 + H_2O$	Soln			X					
			$N_2O_3 + CO_2$	Gas			X					
Soln + Gas	Treat w/$Mg(OH)_2$ soln	3	$MgCl + Mg(NO_2)_2 + MgCO_3 + Mg(NO_3)_2 + Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Slurry								
Slurry	Filter & wash	4	$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Damp solid				$Mg(NO_3)_2 + Mg(OH)_2 + MgCl + Mg(NO_2)_2 + MgCO_3 + H_2O$	Dilute soln *E			
$Mg_3(AsO_4)_2 + Mg(OH)_2 + H_2O$	Evaporate (Optional)	5	$Mg_3(AsO_4)_2+Mg(OH)_2$	Solid				H_2O	Vapor			X

NAME: Mannitol Hexanitrate **I.D. NO.** 532

FORMULA: $C_6H_8(NO_3)_6$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	18
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_8(NO_3)_6$	Controlled incineration w/ afterburner & precipitator, condense (200C) & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides	Solid			x	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2	$Hg + H_2O$	liquid								

NAME: Mercuric Fulminate **I.D. NO.** 533

FORMULA: $Hg(ONC)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Hg(ONC)_2$	Controlled incineration w/ afterburner & precipitator & condense (20ºC) scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid liquid			X	$NaNO_x + Na_2CO_3 + NaCH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME: Nickel Cyanide I.D. NO. 295

FORMULA: $Ni(CN)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	22
ACCEPT. FORM:	$NiO + H_2O$ Damp Solid		2	1
IDEAL FORM:	NiO Solid		4	1

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Ni(CN)_2$	Oxidation w/hypochlorite ion (NaOCl) assumed	1	$Ni(OH)_2 + NiCO_3 + NaCl + N_2 + NaOCl + H_2O$	Slurry			x	$CO_2 + N_2$	Gas			x
Slurry	Evaporate @ 240°C	2	NiO + NaCl	Solid				$CO_2 + O_2 + N_2 + H_2O$	Gas			x
NiO + NaCl	Dilute, filter & wash	3	$NiO + H_2O$	Damp solid				$NaCl + H_2O$	Dilute soln *E			
$NiO + H_2O$	Evaporate (Optional)	4	NiO	Solid				H_2O	Vapor			x

NAME: Nitroglycerin

FORMULA: $C_3H_5(ONO_2)_3$

I.D. NO. 307

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_3H_5(ONO_2)_3$	Controlled incineration w/ afterburner & precipitator, condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid liquid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME: Pentaerythritol Tetranitrate (PETN) **I.D. NO.** 319

FORMULA: $C(CH_2NO_3)_4$

	FORMULA & DESCRIPTION			**T.L.***	**H.I.***
INITIAL FORM:	As obsolete munitions			0	20
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					**NONTOXIC**				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$C(CH_2NO_3)_4$	Controlled incineration w/ afterburner & precipitator, condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides $Hg + H_2O$	Solid Liquid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
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T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Picric Acid

I.D. NO. 338

FORMULA: $(NO_2)_3C_6H_2OH$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	21
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(NO_2)_3C_6H_2OH$	Controlled incineration w/ afterburner & precipitator, condense @ 20ºC & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides Hg + H_2O	Solid liquid			X	$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
Hg + H_2O	Purify & recycle	2										

NAME: Potassium Chromate I.D. NO. 343

FORMULA: K_2CrO_4

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Sludge		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
K_2CrO_4	Reduction w/SO_2	1	$K_2SO_3 + Cr_2(SO_4)_3 + SO_2 + H_2O$	Slurry			X					
Slurry	Precipitation by adjusting PH ≥ 9.5 (NaOH assumed)	2	$Cr(OH)_3$ $K_2SO_3 + Na_2SO_4 + Na_2SO_3 + NaOH + KOH + H_2O$	Precipitate Soln								
Precipitate + soln	Filter & dilute filtrate	3	$Cr(OH)_3 + H_2O$	Sludge				$Na_2SO_3 + KOH + Na_2SO_4 + K_2SO_3 + NaOH + H_2O$	Dilute soln *E			
$Cr(OH)_3$	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			X

NAME: Potassium Dichromate **I.D. NO.** 345

FORMULA: $K_2Cr_2O_7$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Sludge		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$K_2Cr_2O_7$	Reduction w/SO_2	1	$K_2SO_3 + Cr_2(SO_4)_3 + SO_2 + H_2O$	Slurry			X					
Slurry	Precipitation by adjusting PH 9.5 (NaOH assumed)	2	$Cr(OH)_3$ $K_2SO_3 + Na_2SO_4 + KOH + Na_2SO_3 + NaOH + H_2O$	Precipitate soln								
Precipitate + soln	Filter & dilute filtrate	3	$Cr(OH)_3 + H_2O$	Sludge				$Na_2SO_3 + KOH + K_2SO_3 + Na_2SO_4 + NaOH + H_2O$	Dilute soln *E			
$Cr(OH)_3 + H_2O$	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			X

NAME: Potassium Dinitrobenzfuroxan (KDNBF) **I.D. NO.** 536

FORMULA: $C_8H_4N_4O_6K$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	20
ACCEPT. FORM:	Metal oxides + PbO + KOH	Solid		1	3
IDEAL FORM:	Metal oxides + PbO + KOH	Solid		1	3

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$C_{10}H_4N_4O_6K$	Controlled incineration w/ afterburner & precipitator, condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + KOH + metal oxides Hg + H_2O	Damp solid Liquid			 X	$NaNO_x$ + Na_2CO_3 + NaOH + H_2O	Dilute soln *E			
Hg + H_2O	Purify & recycle	2										

NAME. Silver Cyanide

I.D. NO. 370

FORMULA: AgCN

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	22
ACCEPT. FORM:	$AgCl + H_2O$	Damp solid		2	2
IDEAL FORM:	AgCl	Solid		3	2

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
AgCN	Oxidation w/hypochlorite ion (NaOCl assumed)	1	$AgCl + Na_2CO_3 + NaOH + N_2 + NaOCl + H_2O$	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Filter & wash	2	$AgCl + H_2O$	Damp solid				$NaOH + NaOCl + N_2 + Na_2CO_3 + H_2O$	Dilute soln *E			X
$AgCl + H_2O$	Evaporate (Optional)	3	AgCl	Solid				H_2O	Vapor			X

NAME: Smokeless Gunpowder

I.D. NO. 541

FORMULA: (Variable)

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As munitions			0	14
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
#541	Controlled incineration w/ afterburner & precipitator, condense @ 20^{o}C & scrub gases w/dilute caustic soln (NaOH assumed)	1	PbO + metal oxides Hg + H_2O	Solid liquid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
Hg + H_2O	Purify & recycle	2										

NAME: Sodium Chromate I.D. NO. 386

FORMULA: Na_2CrO_4

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$	Sludge		3	4
IDEAL FORM:	Cr_2O_3	Crystals		4	2

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	EVOLVES GAS	EXPLOSIVE	FLAMMABLE	NONTOXIC NAME	NONTOXIC FORM	EVOLVES GAS	EXPLOSIVE	FLAMMABLE
Na_2CrO_4	Reduction w/SO_2	1	$Cr_2(SO_4)_3 + Na_2SO_3 + SO_2 + H_2O$	Slurry	X							
Slurry	Precipitation by adjusting PH ≥ 9.5 (NaOH assumed)	2	$Cr(OH)_3$ $NaOH + Na_2SO_4 + Na_2SO_3 + H_2O$	Precipitate soln								
Soln + precipitate	Filter & dilute filtrate	3	$Cr(OH)_3 + H_2O$	Sludge				$Na_2SO_3 + Na_2SO_4 + NaOH + H_2O$	Dilute soln *E			
$Cr(OH)_3 + H_2O$	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor	X		

NAME: Sodium Dichromate

I.D. NO. 379

FORMULA: $Na_2Cr_2O_7$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	10
ACCEPT. FORM:	$Cr(OH)_3 + H_2O$ Sludge		3	4
IDEAL FORM:	Cr_2O_3 Crystals		4	2

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Na_2Cr_2O_7$	Reduction w/SO_2	1	$Cr_2(SO_4)_3 + Na_2SO_3 + SO_2 + H_2O$	Slurry			X					
Slurry	Precipitation by adjusting PH ≥ 9.5 (NaOH assumed)	2	$Cr(OH)_3$ $Na_2SO_4 + NaOH + Na_2SO_3 + H_2O$	Precipitate soln								
Soln + precipitate	Filter & dilute filtrate	3	$Cr(OH)_3 + H_2O$	Sludge				$NaSO_3 + Na_2SO_4 + NaOH + H_2O$	Dilute soln *E			
Sludge	Evaporate w/heat (Optional)	4	Cr_2O_3	Crystals				H_2O	Vapor			X

NAME: TNT **I.D. NO.** 418

FORMULA: $C_7H_5O_6N_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	19
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_7H_5O_6N_3$	Controlled incineration w/ afterburner & precipitator, condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	$Hg + H_2O$ Metal oxides + PbO	Liquid Solid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

NAME: Tetrazene I.D. NO. 542

FORMULA: $C_2H_7ON_9$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	18
ACCEPT. FORM:	Metal oxides + PbO	Solid		1	3
IDEAL FORM:	Metal oxides + PbO	Solid		1	3

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_2H_7ON_9$	Controlled incineration w/ afterburner & precipitator, condense @ 200C & scrub gases w/dilute caustic soln (NaOH assumed)	1	$Hg + H_2O$ Metal oxides + PbO	Liquid Solid			X	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2										

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

Pages 406 through 444 of Appendix B-3, Waste Treatment Procedures, refer to Table 9, CANDIDATE WASTES WHICH MUST BE TREATED AND WHOSE TREATMENT PRODUCTS CONSTITUTE AN ENVIRONMENTAL RISK ONLY. (Candidates listed in alphabetical order by name.)

NAME: Acrolein **I.D. NO.** 8

FORMULA: C_3H_4O

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	22
ACCEPT. FORM:	$CO_2 + H_2O$	Gas		1	0
IDEAL FORM:	Same as above			1	0

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		x	
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Gas	
	NAME	$CO_2 + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Dilute: concentrate by submerged combustion. Conc: incineration w/afterburner	
	NAME	C_3H_4O	

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Ammonium Picrate, Dry & Wet — I.D. NO. 27, 28

FORMULA: $NH_4C_6H_2N_3O_7$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	21
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln.		1	E

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute Soln *E	
	NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration w/afterburner & caustic scrubber (dilute soln) (NaOH assumed)	
	NAME	$NH_4C_6H_2N_3O_7$	

NAME: Boron Hydrides **I.D. NO.** 61, 505

FORMULA: B_2H_6, B_6H_{10}, $B_{10}H_5$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	25
ACCEPT. FORM:	$H_3BO_3 + H_2O$ Dilute soln.		1	E
IDEAL FORM:	Same as above		1	E

*E = ENVIRONMENTAL RISK
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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute Soln *E	
NONTOXIC	NAME	$H_3BO_3 + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
TOXIC	NAME		
T.L.*		1	
	TREATMENT	Incineration w/aqueous scrubbing	
	NAME	#61, 505	

NAME: Calcium Cyanide I.D. NO. 91

FORMULA: $Ca(CN)_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$CaCl_2 + CaCO_3 + N_2 + Ca(OCl)_2 + H_2O$	Soln.		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS: TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Ca(CN)_2$	Conc: dilution	1						$CaCl_2 + CaCO_3 + N_2 + Ca(OCl)_2 + H_2O$	Soln *E			x
	Dilute: oxidation w/hypochlorite ion ($Ca(OCl)_2$ assumed)	1						$N_2 + CO_2$	Gas			x

NAME: Chlordane

FORMULA: $C_{10}H_6Cl_8$

I.D. NO. 484

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	12
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln.		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_{10}H_6Cl_8$	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln. (NaOH assumed)	1						$NaCl + Na_2CO_3 + NaOH + H_2O$ Ash (possible)	Dilute soln *E Powder			

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Chlorine **I.D. NO.** 105

FORMULA: Cl_2

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	21
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaOCl + NaOH + H_2O$ Soln		1	E

TREATMENT PRODUCTS			
EVOLVES GAS		x	
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Soln *E (Recycle)	
	NAME	$NaOCl + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Scrub w/caustic soln (NaOH assumed)	
	NAME	Cl_2	

NAME: Chlorine Trifluoride & Pentafluoride **I.D. NO.** 106

FORMULA: ClF_3, ClF_5

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	25
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaOCl + NaOH + H_2O$	Soln		2	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
ClF_3, ClF_5	Reaction w/charcoal	1	$Cl_2 + CF_4$	Gas			X	C	Solid			
$Cl_2 + CF_4$	Scrub w/caustic soln (NaOH assumed)	2						$NaOCl + NaOH + H_2O$	Soln *E (Recycle)			X
								CF_4	Gas			X

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*H.I. = HAZARD INDEX
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NAME: Diazodinitrophenol (DDNP) I.D. NO. 521

FORMULA: $C_6H_2O_5N_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	20
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

NAME	$C_6H_2O_5N_4$	
TREATMENT	Controlled incineration as a slurry w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	
T.L.*	1	
TREATMENT PRODUCTS — TOXIC — NAME		
TREATMENT PRODUCTS — TOXIC — FORM		
FLAMMABLE		
EXPLOSIVE		
EVOLVES GAS		
TREATMENT PRODUCTS — NONTOXIC — NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
TREATMENT PRODUCTS — NONTOXIC — FORM	Dilute soln *E	
FLAMMABLE		
EXPLOSIVE		
EVOLVES GAS		

NAME: Dimethyl Sulfate (Methyl Sulfate) **I.D. NO.** 160

FORMULA: $(CH_3)_2SO_4$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:					
ACCEPT. FORM:	Does not apply			0	20
IDEAL FORM:	$Na_2SO_3 + Na_2CO_3 + NaOH + H_2O$	Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$(CH_3)_2SO_4$	Conc: dilution Dilute: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$Na_2SO_3 + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			

NAME: Dinitro Cresols (DNOC) I.D. NO. 162

FORMULA: $C_7H_6O_5N_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	13
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_7H_6O_5N_2$	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Ash (possible)	Dilute soln. *E Powder			

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*H.I. = HAZARD INDEX
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NAME: Dinitrotoluene (DNT)

I.D. NO. 165

FORMULA: $(NO_2)_2C_6H_3CH_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	21
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute Soln		1	E

TREATMENT PRODUCTS			
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E Powder	
	NAME	$NaNO_x + Na_2CO_3 +$ $NaOH + H_2O$ Ash	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
TREATMENT		Mix w/$NaHCO_3$ & solid combustibles & incin w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	
NAME		$(NO_2)_2C_6H_3CH_3$	

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Dipentaerythritol Hexanitrate (DPEHN) I.D. NO.522

FORMULA: $C_{10}H_{16}N_6O_{19}$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	20
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln		1	E

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration as a slurry w/afterburner & scrubbing w/dilute caustic soln (NaOH assumed)	
	NAME	$C_{10}H_{16}N_6O_{19}$	

NAME: Gelatinized Nitrocellulose (PNC) **I.D. NO.** 523

FORMULA: $C_{12}H_{17}(ONO_2)_3O_7$ to $C_{12}H_{14}(ONO_2)_6O_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	18
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute Soln.		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
PNC	Controlled incineration as a slurry w/afterburner & scrubbing w/dilute caustic soln. (NaOH assumed)	1						$NaNO_x + Na_2CO_3 +$ $NaOH + H_2O$	Dilute soln *E			

NAME: Glycol Dinitrate (DDN) I.D. NO. 525

	FORMULA: $C_2H_4(ONO_2)_2$			
	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	23
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute Soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS									
			TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$C_2H_4(ONO_2)_2$	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			

NAME: Hydrogen Sulfide **I.D. NO.** 221

FORMULA: H_2S

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	Na_2SO_3 + NaOH + H_2O	Dilute soln		3 or 4	E

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
H_2S												
Sour water	Strip w/steam	1	H_2S + H_2O	Gas	X	X	X	H_2O	Liquid			
Sour gas	Scrub w/amine soln	1	H_2S + Amine	Soln	X	X	X					
			H_2S (residual)	Gas	X	X	X					
H_2S + Amine	Amine regeneration w/heat	2	H_2S	Gas	X	X	X	Amine	Soln (Recycle)			
H_2S + H_2O or	Claus-Beavon Process	2	SO_2	Gas			X	S	Solid (Recycle)	X		
H_2S (residual) or		2										
H_2S (amine regeneration)		3										
SO_2	Scrub w/dilute caustic soln (NaOH assumed)	3 or 4						Na_2SO_3 + NaOH + H_2O	Dilute soln *E			

NAME: Mannitol Hexanitrate **I.D. NO.** 532

FORMULA: $C_6H_8(NO_3)_6$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	18
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute Soln		1	E

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration w/ afterburner & dilute caustic scrubber (NaOH assumed)	
	NAME	$C_6H_8(NO_3)_6$	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME: Methyl Parathion **I.D. NO.** 274

FORMULA: $C_8H_{10}O_5SPN$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	22
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x+Na_2CO_3+Na_2SO_3+Na_3PO_4+NaOH+H_2O$ Dilute Soln		1	E

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + Na_2SO_3 + Na_3PO_4 + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
TREATMENT		Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	
NAME		$C_8H_{10}O_5SPN$	

NAME: Nickel Carbonyl **I.D. NO.** 293

FORMULA: $Ni(CO)_4$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Does not apply			1	1
IDEAL FORM:	Ni	Solid		1	1

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS: TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Ni(CO)_4$	Carefully expose to air	1						Ni CO_2	Solid Gas			x
Ni	Recycle (Optional)											

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Nitrocellulose

I.D. NO. 534

FORMULA: $[C_6H_{10}O_5(NO_2)_x]_n$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions			0	18
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaNO_3$+NaOH+Cellulose+H_2O	Dilute soln		2	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$[C_6H_{10}O_5(NO_2)_x]_n$	Treat w/10% NaOH soln	1	$NaNO_3$ + cellulose + NaOH + H_2O	Slurry								
Slurry	Dilute	2						$NaNO_3$ + NaOH + cellulose + H_2O	Dilute soln *E			

NAME: Nitrocellulose **I.D. NO.** 534

FORMULA: $[C_6H_{10}O_5(NO_2)_x]_n$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	18
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

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*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS									
			TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$[C_6H_{10}O_5(NO_2)_x]_n$	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute Soln *E			

NAME: Nitrogen Mustard I.D. NO. 306

FORMULA: $C_6H_{12}Cl_3N$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	12
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaCl + NaOH + H_2O$ Dilute soln		1	E

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
			NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_6H_{12}Cl_3N$	Dilute: concentrate by adjusting PH ≥ 7 & centrifuge. Treat product same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x + Na_2CO_3 +$ $NaCl + NaOH +$ H_2O	Dilute soln *E			

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Nitroglycerin **I.D. NO.** 307

FORMULA: $C_3H_5(ONO_2)_3$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	21
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 +$ $NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	$C_3H_5(ONO_2)_3$	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Parathion **I.D. NO.** 321

FORMULA: $C_{10}H_{14}NO_5PS$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	22
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x+Na_2CO_3+Na_2SO_3+Na_3PO_4+NaOH+H_2O$ Dilute soln		1	E

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS: TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_{10}H_4NO_5PS$	Dilute: concentrate w/activated carbon beds w/regeneration of carbon in furnace. Treat products same as below. Conc: incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x$ Na_2CO_3 + Na_2SO_3 + Na_3PO_4 + $NaOH$ + H_2O	Dilute Soln *E			

NAME: Pentaborane **I.D. NO.** 505

FORMULA: B_5H_9

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	25
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$H_3BO_3 + H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute Soln *E	
	NAME	$H_3BO_3 + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Incineration w/aqueous scrubbing	
	NAME	B_5H_9	

NAME: Pentaerythritol Tetranitrate (PETN) I.D. NO. 319

FORMULA: $C(CH_2NO_3)_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Non-munitions		0	20
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute Soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME	TREATMENT	T.L.*	TREATMENT PRODUCTS									
			TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
			NAME	FORM				NAME	FORM			
$C(CH_2NO_3)_4$	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNo_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME: Perchloric Acid (72% Strength) **I.D. NO.** 324

FORMULA: $HClO_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	24
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$Na_2SO_4+Na_2SO_3+NaCl+NaOH+H_2O$ Dilute soln		2	E

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$HClO_4$	Dilute & reduce w/SO_2	1	$H_2SO_4 + HCl +$ $H_2SO_3 + H_2O$	Soln			x					
			SO_2	Gas (Re-cycle)			x					
Soln	Treat w/caustic & dilute (NaOH assumed)	2						$Na_2SO_4 + Na_2SO_3 +$ $NaCl + NaOH +$ H_2O	Dilute soln *E			

NAME: Perchloryl Fluoride

I.D. NO. 326

FORMULA: ClO_3F

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	18
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaOCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		2	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
ClO_3F	Reaction w/charcoal	1	$Cl_2+CF_4+CO_2$	Gas			X					
$Cl_2+CF_4+CO_2$	Scrub w/dilute caustic soln (NaOH assumed)	2						$NaOCl+Na_2CO_3+NaOH+H_2O$ CF_4	Dilute soln *E Gas			X X

NAME: Picric Acid **I.D. NO.** 338

FORMULA: $(NO_2)_3C_6H_2OH$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	21
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3$ $NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	$(NO_3)_2C_6H_2OH$	

NAME: Potassium Cyanide **I.D. NO.** 344

FORMULA: KCN

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$KCl+K_2CO_3+KOH+NaOH+Na_2CO_3+NaOCl+N_2+H_2O$	Soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
KCN	Oxidation w/hypochlorite ion (NaOCl assumed)	1						$CO_2 + N_2$ $KCl + NaOH + Na_2CO_3 + KOH + N_2 + K_2CO_3 + NaOCl + H_2O$	Gas Soln *E			X X

NAME: Potassium Dinitrobenzfuroxan (KDNBF) **I.D. NO.** 536

FORMULA: $C_8H_4N_4O_6K$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	20
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x+Na_2CO_3+KOH+NaOH+H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + KOH + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	$C_8H_4N_4O_6K$	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Smokeless Gunpowder — I.D. NO. 541

FORMULA: (Variable)

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	14
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

TREATMENT PRODUCTS		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
	NONTOXIC	FORM	Dilute soln *E	
		NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
	TOXIC	FORM		
		NAME		
		T.L.*	1	
		TREATMENT	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	
		NAME	#541	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Sodium Cyanide　　**I.D. NO.** 387

FORMULA: NaCN

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	24
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + N_2 + NaOCl + H_2O$	Soln		1	E

TREATMENT PRODUCTS		EVOLVES GAS	x x	
		EXPLOSIVE		
		FLAMMABLE		
	NONTOXIC	FORM	Gas Soln *E	
		NAME	$CO_2 + N_2$ $NaCl + Na_2CO_3 +$ $NaOH + N_2 +$ $NaOCl + H_2O$	
		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
	TOXIC	FORM		
		NAME		
		T.L.*	1	
		TREATMENT	Oxidation w/hypochlorite ion (NaOCl assumed)	
		NAME	NaCN	

NAME: Sulphur Mustard I.D. NO. 543

FORMULA: $C_4H_8SCl_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	24
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$Na_2CO_3+Na_2SO_3+NaCl+NaOH+H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS	EVOLVES GAS			
	EXPLOSIVE			
	FLAMMABLE			
	NONTOXIC	FORM	Dilute soln *E	
		NAME	$Na_2CO_3+Na_2SO_3+NaCl+NaOH+H_2O$	
	EVOLVES GAS			
	EXPLOSIVE			
	FLAMMABLE			
	TOXIC	FORM		
		NAME		
	T.L.*		1	
	TREATMENT		Incineration w/afterburner & * scrub w/dilute caustic soln (NaOH assumed)	
	NAME		$C_4H_8SCl_2$	

NAME: TNT

I.D. NO. 418

FORMULA: $C_7H_5O_6N_3$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	19
ACCEPT. FORM:	Does not apply				
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_7H_5O_6N_3$	Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	1						$NaNO_x+Na_2CO_3+$ $NaOH+H_2O$	Dilute soln *E			

NAME: Tear Gas (CN) (Chloroacetophenone) I.D. NO.422, 107

FORMULA: C_8H_7OCl

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	12
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaCl + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

TREATMENT PRODUCTS	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	NONTOXIC FORM	Dilute soln *E	
	NONTOXIC NAME	$NaCl + Na_2CO_3 +$ $NaOH + H_2O$	
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	TOXIC FORM		
	TOXIC NAME		
	T.L.*	1	
	TREATMENT	Dissolve in benzene (C_6H_6) & incinerate w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	C_8H_7OCl	

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME: Tear Gas, Irritant (CS) I.D. NO. 423

FORMULA: $C_{10}H_6N_2Cl$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	11
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

TREATMENT PRODUCTS

EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	
EVOLVES GAS			
EXPLOSIVE			
FLAMMABLE			
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Hydrolyze w/95 ethyl alcohol + H_2O & incinerate w/after-burner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	$C_{10}H_6N_2Cl$	

NAME: Tetrazene **I.D. NO.** 542

FORMULA: $C_2H_8ON_9$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	18
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x + Na_2CO_3 + NaOH + H_2O$ Dilute soln		1	E

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
NONTOXIC	FORM		Dilute soln *E	
	NAME		$NaNO_x$ Na_2CO_3 + $NaOH + H_2O$	
		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
TOXIC	FORM			
	NAME			
T.L.*			1	
	TREATMENT		Controlled incineration w/ afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME		$C_2H_7ON_9$	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: VX (Persistent Nerve Gas) I.D. NO. 288

FORMULA: $C_{11}H_{26}O_2SNP$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	13
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$NaNO_x+Na_2CO_3+Na_2SO_3+Na_3PO_4+NaOH+H_2O$ Dilute soln		1	E

TREATMENT PRODUCTS	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
NONTOXIC	FORM	Dilute soln *E	
	NAME	$NaNO_x + Na_2CO_3 + Na_2SO_3 + Na_3PO_4 + NaOH + H_2O$	
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
TOXIC	FORM		
	NAME		
T.L.*		1	
	TREATMENT	Incineration w/afterburner & scrub w/dilute caustic soln (NaOH assumed)	
	NAME	$C_{11}H_{26}O_2SNP$	

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Zinc Cyanide

I.D. NO. 457

FORMULA: $Zn(CN)_2$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	23
ACCEPT. FORM:	Does not apply			
IDEAL FORM:	$Zn(OH)_2 + CaCl_2 + CaCO_3 + ZnCO_3 + Ca(OCl)_2 + N_2 + Ca(OH)_2 + H_2O$ Slurry		2	E

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Zn(CN)_2$	Oxidation w/hypochlorite ion ($Ca(OCl)_2$ assumed)	1	$ZnCl_2 + CaCl_2 + Ca(OH)_2 + Zn(OH)_2$ $CaCO_3 + ZnCO_3 + Ca(OCl)_2 + N_2 + H_2O$	Soln			X	$CO_2 + N_2$	Gas			X
Soln	Treat w/excess $Ca(OH)_2$	2						$Zn(OH)_2 + CaCl_2 + CaCO_3 + ZnCO_3 + Ca(OCl)_2 + N_2 + Ca(OH)_2 + H_2O$	Slurry *E			

Pages 446 through 454 of Appendix B-3, Waste Treatment Procedures refer to Table 10, CANDIDATE WASTES FOR WHICH TREATMENT WAS UNAVAILABLE OR INSUFFICIENT AND REQUIRE FURTHER STUDY. (Candidates listed in alphabetical order by name.)

NAME: Gold Fulminate

I.D. NO. 526

FORMULA: Not available

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	As munitions		0	20
ACCEPT. FORM:				
IDEAL FORM:				

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		
	TREATMENT	
	NAME	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Gold Fulminate **I.D. NO.** 526

FORMULA: Not available

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	20
ACCEPT. FORM:				
IDEAL FORM:				

TREATMENT PRODUCTS		
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		

TREATMENT	
NAME	

NAME: Silver Acetylide **I.D. NO.** 537

FORMULA: Ag_2C_2

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	20
ACCEPT. FORM:				
IDEAL FORM:				

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*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		
	TREATMENT	
	NAME	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

NAME: Silver Azide **I.D. NO.** 538

FORMULA: AgN_3

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions		0	20
ACCEPT. FORM:				
IDEAL FORM:				

TREATMENT PRODUCTS	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	NONTOXIC	FORM	
		NAME	
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	TOXIC	FORM	
		NAME	
	T.L.*		
		TREATMENT	
		NAME	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Silver Azide

I.D. NO. 538

FORMULA: AgN_3

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			
ACCEPT. FORM:			0	20
IDEAL FORM:				

TREATMENT PRODUCTS			
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	NONTOXIC	FORM	
		NAME	
	EVOLVES GAS		
	EXPLOSIVE		
	FLAMMABLE		
	TOXIC	FORM	
		NAME	
	T.L.*		

TREATMENT	
NAME	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Silver Styphnate I.D. NO. 539

FORMULA: $Ag_2C_6HN_3O_8$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions		0	21
ACCEPT. FORM:				
IDEAL FORM:				

TREATMENT PRODUCTS		EVOLVES GAS	
		EXPLOSIVE	
		FLAMMABLE	
	NONTOXIC	FORM	
		NAME	
		EVOLVES GAS	
		EXPLOSIVE	
		FLAMMABLE	
	TOXIC	FORM	
		NAME	
	T.L.*		
		TREATMENT	
		NAME	

NAME: Silver Styphnate **I.D. NO.** 539

FORMULA: $Ag_2C_6HN_3O_8$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	21
ACCEPT. FORM:				
IDEAL FORM:				

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		
	TREATMENT	
	NAME	

NAME: Silver Tetrazene **I.D. NO.** 540

FORMULA: Not available

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	As obsolete munitions		0	21
ACCEPT. FORM:				
IDEAL FORM:				

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS	EVOLVES GAS	
	EXPLOSIVE	
	FLAMMABLE	
NONTOXIC	FORM	
	NAME	
	EVOLVES GAS	
	EXPLOSIVE	
	FLAMMABLE	
TOXIC	FORM	
	NAME	
T.L.*		
	TREATMENT	
	NAME	

NAME: Silver Tetrazene I.D. NO. 540

FORMULA: Not available

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:	Nonmunitions		0	21
ACCEPT. FORM:				
IDEAL FORM:				

TREATMENT PRODUCTS

EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
NONTOXIC	FORM	
	NAME	
EVOLVES GAS		
EXPLOSIVE		
FLAMMABLE		
TOXIC	FORM	
	NAME	
T.L.*		
	TREATMENT	
	NAME	

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE CONTAINERS.

Pages 456 through 464 of Appendix B-3, Waste Treatment Procedures, refer to Table 11, CANDIDATE WASTES WHICH ARE NOT RECOMMENDED FOR UNDERGROUND STORAGE IN ANY FORM. (Candidates listed in alphabetical order by name.)

NAME: Bromine Pentafluoride

I.D. NO. 66

FORMULA: BrF_5

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	25
ACCEPT. FORM:	None				
IDEAL FORM:	Br_2	Liquid		2	21

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY.
ALL OTHER LEVELS INCLUDE
CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
BrF_5	Reaction w/charcoal	1	$Br_2 + CF_4$	Gas	x		x					
$Br_2 + CF_4$	Condense in ice cooled trap	2	Br_2	Liquid	x		x	CF_4	Gas			x
Br_2	Recycle											

NAME: Mercuric Chloride I.D. NO. 253

FORMULA: $HgCl_2$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		3	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$HgCl_2$	Treat w/H_2S	1	$HgS + HCl + H_2S + H_2O$	Slurry	X	X	X					
Slurry	Incinerate (360°C) in presence of air, condense & scrub w/caustic soln (NaOH assumed)	2	$Hg + H_2O$ $NaCl + Na_2SO_3 + NaOH + H_2O$	Liquid Solution			X					
Solution	Dilute	3						$NaCl + Na_2SO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Separate Hg	3	Hg	Liquid			X	H_2O	Liquid			
Hg	Recycle											

NAME: Mercuric Cyanide

FORMULA: $Hg(CN)_2$

I.D. NO. 254

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	25
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		4	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Hg(CN)_2$	Oxidation w/hypochlorite ion (NaOCl assumed)	1	$HgCl_2 + Hg_2CO_3 + HgO + Na_2CO_3 + NaCl + NaOH + NaOCl + H_2O$	Slurry			X	$CO_2 + N_2$	Gas			X
Slurry	Treat w/$NaBH_4$	2	$Hg + H_2 + H_2O$	Gas	X	X	X					
			$Na_2CO_3 + NaCl + NaOH + Na_3BO_3 + Hg + H_2O$	Slurry			X					
$Hg + H_2 + H_2O$	Mist eliminator	3	$Hg + H_2O$	Liquid			X	H_2	Gas	X	X	X
Slurry	Remove Hg & dilute filtrate	3	Hg	Liquid			X	$Na_2CO_3 + NaCl + NaOH + Na_3BO_3 + H_2O$	Dilute soln *E			
$Hg + H_2O$ & Hg	Purify & recycle	4	Hg	Liquid			X	H_2O	Liquid			

NAME: Mercuric Diammonium Chloride

I.D. NO. 503

FORMULA:	$Hg(NH_3)_2Cl_2$			
	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	10
ACCEPT. FORM:	None			
IDEAL FORM:	Hg Liquid		4	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
		T.L.*	TOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC		FLAMMABLE	EXPLOSIVE	EVOLVES GAS
NAME	TREATMENT		NAME	FORM				NAME	FORM			
$Hg(NH_3)_2Cl_2$	Decompose in hot H_2O	1	$HgCl_2 + NH_4OH + H_2O$	Soln			X					
Soln	Treat w/H_2S	2	$HgS + (NH_4)_2S + HCl + H_2S + H_2O$	Slurry	X	X	X					
Slurry	Incinerate & condense & scrub w/caustic soln (NaOH assumed)	3	$Hg + H_2O$ $Na_2SO_3 + NaNO_x + NaCl + NaOH + H_2O$	Liquid Soln			X					
Liquid	Separate Hg	4	Hg	Liquid			X	H_2O	Liquid			
Soln	Dilute	4						$NaNO_x + Na_2SO_3 + NaCl + NaOH + H_2O$	Dilute soln *E			
Hg	Recycle											

NAME: Mercuric Fulminate

FORMULA: $Hg(ONC)_2$

I.D. NO. 533

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:	Nonmunitions			0	21
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		2	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

			TREATMENT PRODUCTS									
			TOXIC					NONTOXIC				
NAME	**TREATMENT**	**T.L.***	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**	**NAME**	**FORM**	**FLAMMABLE**	**EXPLOSIVE**	**EVOLVES GAS**
$Hg(ONC)_2$	Controlled incineration w/afterburner & condense @ 20°C & scrub gases w/dilute caustic soln (NaOH assumed)	1	$Hg + H_2O$	Liquid			x	$NaNO_x + Na_2CO_3 + NaOH + H_2O$	Dilute soln *E			
$Hg + H_2O$	Purify & recycle	2	Hg	Liquid			x	H_2O	Liquid			

NAME: Mercuric Nitrate **I.D. NO.** 255

FORMULA: $Hg(NO_3)_2 \cdot H_2O$

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	16
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		2	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$Hg(NO_3)_2 \cdot H_2O$	Incinerate, condense & scrub w/caustic soln. (NaOH assumed)	1	$Hg + H_2O$ $NaNO_x + NaOH + H_2O$	Liquid Soln			x x					
Liquid soln	Remove Hg Dilute	2 2	Hg	Liquid			x	H_2O $NaNO_x + NaOH + H_2O$	Liquid Dilute soln *E			
Hg	Recycle											

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Mercuric Sulfate I.D. NO. 256

FORMULA: $HgSO_4$

	FORMULA & DESCRIPTION		T.L.*	H.I.*
INITIAL FORM:			0	10
ACCEPT. FORM:	None			
IDEAL FORM:	Hg Liquid		2	10

TREATMENT PRODUCTS

NAME	TREATMENT	T.L.*	TOXIC NAME	TOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NONTOXIC NAME	NONTOXIC FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$HgSO_4$	Incinerate & condense & scrub w/caustic soln. (NaOH assumed)	1	$Hg + H_2O$ $Na_2SO_3 + NaOH + H_2O$	Liquid Soln			x					
Liquid	Remove Hg	2	Hg	Liquid			x	H_2O	Liquid			
Soln	Dilute	2						$Na_2SO_3 + NaOH + H_2O$	Dilute soln *E			
Hg	Recycle			*								

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

NAME: Mercury I.D. NO. 257

FORMULA: Hg

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	10
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		0	10

TREATMENT PRODUCTS		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
	NONTOXIC	FORM		
		NAME		
		EVOLVES GAS		
		EXPLOSIVE		
		FLAMMABLE		
	TOXIC	FORM		
		NAME		
T.L.*				
		TREATMENT	Recycle	
		NAME	Hg	

NAME: Organic Mercury Compounds

I.D. NO. 258

FORMULA: $C_8H_8O_2Hg$ & $Hg(CH_3)_2$ (as examples)

	FORMULA & DESCRIPTION			T.L.*	H.I.*
INITIAL FORM:				0	16
ACCEPT. FORM:	None				
IDEAL FORM:	Hg	Liquid		2	10

*E = ENVIRONMENTAL RISK
*H.I. = HAZARD INDEX
*T.L. = TREATMENT LEVEL
T.L. = 0 = CONTAINERIZED ONLY. ALL OTHER LEVELS INCLUDE CONTAINERS.

TREATMENT PRODUCTS

			TOXIC					NONTOXIC				
NAME	TREATMENT	T.L.*	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS	NAME	FORM	FLAMMABLE	EXPLOSIVE	EVOLVES GAS
$C_8H_8O_2Hg$ & $Hg(CH_3)_2$	Incinerate w/afterburner & condense & scrub w/caustic soln. (NaOH assumed)	1	$Hg + H_2O$	Liquid			x					
			$NaNO_x + Na_2CO_3 + Na_2SO_3 + NaCl + NaOCl + NaOH + H_2O$	Slurry			x					
Liquid	Remove Hg	2	Hg	Liquid			x	H_2O	Liquid			
Slurry	Dilute	2						$NaNO_x + Na_2CO_3 + Na_2SO_3 + NaCl + NaOCl + NaOH + H_2O$	Dilute soln *E			x
Hg	Recycle											

APPENDIX B-4

PROJECTION AND GEOGRAPHIC DISTRIBUTION OF CANDIDATE WASTE VOLUMES

S.I.C. code: 22

Industry: Textile mill products

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide					
83	Cadmium Chloride		14.0			
322	Pentachlorophenol		3.0			
376	Sodium Arsenate					
	Acceptable for underground storage after treatment					
22	Ammonium Dichromate		1.7			
345	Potassium Dichromate		1.7	8.10 (286)	8.78 (310)	9.54 (337)
386	Sodium Chromate		1.7			
379	Sodium Dichromate		1.7	270.43 (9,550)	293.36 (10,360)	321.68 (11,360)
	Underground storage of treatment products is optional					
338	Picric Acid					
	Not recommended for underground storage					
253	Mercuric Chloride		3.0			
255	Mercuric Nitrate		3.0			

S.I.C. code: 22

Industry: Textile mill products

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
345	Potassium Dichromate	38	14	2		39	5			2
386	Sodium Chromate	10	18	3	1	57	3	1	1	6
379	Sodium Dichromate	38	14	2		39	5			2

S.I.C. code: 24

Industry: Lumber and wood

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Not recommended for underground storage									
253	Mercuric Chloride	1	3	12	6	27	14	17	4	16

S.I.C. code: 26

Industry: Paper and allied products

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
322	Pentachlorophenol		3.0	0.16 (5.6)	0.18 (6.4)	0.21 (7.4)
	Acceptable for underground storage after treatment					
345	Potassium Dichromate		1.7			
	Underground storage of treatment products is optional					
105	Chlorine		6.5			
160	Dimethyl Sulfate	1%	3.0	0.64 (22.5)	0.74 (26.1)	0.86 (30.2)
221	Hydrogen Sulfide	0.033% (330 ppm)	3.0	1,293.80 (45,690)	1,499.87 (52,967)	1,738.76 (61,404)
	Not recommended for underground storage					
258	Organic Mercury compounds		3.0			

S.I.C. code: 26

Industry: Paper and allied products

		Percentage Distribution								
		Bureau of Census region								
ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Underground storage of treatment products is optional									
160	Dimethyl Sulfate		50			50				

S.I.C. code: 2812

Industry: Chlor-alkali industry

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
105	Chlorine		6.5	40,210.12 ($1.42x10^6$)	50,687.41 ($1.79x10^6$)	63,996.39 ($2.26x10^6$)
	Not recommended for underground storage					
257	Mercury	29%	6.5	0.54 (19)	0.73 (26)	1.01 (36)

S.I.C. code: 2812

Industry: Chlor-alkali industry

ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
		Percentage Distribution Bureau of Census region								
	Underground storage of treatment products is optional									
105	Chlorine	1	19	9		20	43	5		3
	Not recommended for underground storage									
257	Mercury	1	19	9		20	43	5		3

S.I.C. code: 2819

Industry: Industrial inorganic chemicals

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide					
83	Cadmium Chloride		14.0			
85	Cadmium Oxide		14.0			
86	Cadmium Phosphate		14.0			
481	Cadmium Sulfate		14.0			
	Acceptable for underground storage after treatment					
21	Ammonium Chromate		1.7			
22	Ammonium Dichromate		1.7			
36	Antimony Pentafluoride					
43	Antimony Trifluoride					
50	Arsenic Trichloride					
82	Cadmium, Powdered					
84	Cadmium Cyanide					
114	Chromic Acid		1.7			
128	Cuprous (Copper) Cyanide					
200	Fluorine					
343	Potassium Chromate		1.7	100.58 (3,552)	109.42 (3,864)	119.05 (4,204)
345	Potassium Dichromate		1.7	0.85 (30)	0.92 (33)	1.01 (36)
386	Sodium Chromate		1.7	3,352.87 (118,405)	3,645.44 (128,737)	3,962.59 (139,937)
379	Sodium Dichromate	0.05% (500 ppm)	1.7	28.23 (997)	30.70 (1,084)	33.41 (1,180)
480	Cadmium Potassium Cyanide		14.0			

S.I.C. code: 2819

Industry: Industrial inorganic chemicals

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Underground storage of treatment products is optional					
61, 505	Boron Hydrides					
91	Calcium Cyanide					
105	Chlorine		6.5	1,370.54 (48.4×10^3)	1,730.17 (61.1×10^3)	2,183.24 (77.1×10^3)
106	Chlorine Trifluoride					
324	Perchloric Acid (72%)					
326	Perchloryl Fluoride					
338	Picric Acid					
387	Sodium Cyanide					
457	Zinc Cyanide					
	Not recommended for underground storage					
253	Mercuric Chloride		3.0			
503	Mercuric Diammonium Chloride		3.0			
254	Mercuric Cyanide		3.0			
255	Mercuric Nitrate		3.0			
256	Mercuric Sulfate		3.0			
257	Mercury		3.0			

S.I.C. code: 2819

Industry: Industrial inorganic chemicals

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
200	Fluorine	1	10	16	7	15	21	15	5	10
343	Potassium Chromate	19	6	1	1	60	10	1	1	1
345	Potassium Dichromate	19	6	1	1	60	10	1	1	1
386	Sodium Chromate	15	24	3	24	3	11	15		5
	Underground storage of treatment products is optional									
387	Sodium Cyanide	1	10	16	7	15	21	15	5	10
	Not recommended for underground storage									
254	Mercuric Cyanide		100							

S.I.C. code: 282

Industry: Plastics

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
8	Acrolein					
165	Dinitrotoluene					
	Not recommended for underground storage					
253	Mercuric Chloride		3.0			
258	Organic Mercury Compounds	.0015% (15 ppm)	3.0	0.29 (10.2)	0.34 (11.8)	0.39 (13.7)

S.I.C. code: 282

Industry: Plastics

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Not recommended for underground storage									
257	Mercury	5	12	10	2	40	18	10		3
253	Mercuric Chloride	10	21	21	16	14	7	10		2
258	Organic Mercury Compounds	5	12	10	2	40	18	10		3

S.I.C. code: 2834 (3843)

Industry: Pharmaceutical preparations

ID no.	Waste name	Percentage Distribution								
		Bureau of Census region								
		(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Not recommended for underground storage									
257	Mercury	6	35	18	9	10	3	6	1	12
258	Organic Mercury Compounds	6	35	18	9	10	3	6	1	12

S.I.C. code: 2842

Industry: Polishes and sanitation

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
135	2, 4-D		1.0			
136	DDD					
137	DDT					
	Underground storage of treatment products is optional					
105	Chlorine		6.5	685.27 (24.2×10^3)	863.67 (30.5×10^3)	1,090.20 (38.5×10^3)

S.I.C. code: 2851

Industry: Paints and allied products

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
83	Cadmium Chloride		14.0			
85	Cadmium Oxide	3.0%	14.0	0.62 (22)	1.20 (42.5)	2.32 (81.9)
481	Cadmium Sulfate		14.0			
490	Copper Acetoarsenite					
322	Pentachlorophenol		3.0			
	Acceptable for underground storage after treatment					
21	Ammonium Chromate		1.7	99.31 (3,507)	108.06 (3,816)	117.54 (4,151)
114	Chromic Acid		1.7	3.31 (117)	3.60 (127)	3.94 (139)
128	Cuprous (Copper) Cyanide	2%				
129	Cyanides		1.7	125.67 (4,438)	136.72 (4,828)	148.74 (5,253)
345	Potassium Dichromate		1.7			
386	Sodium Chromate		1.7			
379	Sodium Dichromate		1.7			
	Not recommended for underground storage					
257	Mercury	.0125% (125 ppm)	3.0	0.07 (2.3)	0.07 (2.6)	0.08 (2.9)
258	Organic Mercury Compounds		3.0	4.98 (176)	5.61 (198)	6.37 (225)

S.I.C. code: 2851

Industry: Paints and allied products

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
83	Cadmium Chloride	3	23	30	6	10	4	8	1	15
85	Cadmium Oxide	3	23	30	6	10	4	8	1	15
481	Cadmium Sulfate	3	23	30	6	10	4	8	1	15
	Acceptable for underground storage after treatment									
21	Ammonium Chromate	3	23	30	6	10	4	8	1	15
114	Chromic Acid	3	23	30	6	10	4	8	1	15
129	Cyanides	3	23	30	6	10	4	8	1	15
345	Potassium Dichromate	3	23	30	6	10	4	8	1	15
386	Sodium Chromate	3	23	30	6	10	4	8	1	15
379	Sodium Dichromate	3	23	30	6	10	4	8	1	15
	Not recommended for underground storage									
257	Mercury	3	23	30	6	10	4	8	1	15
258	Organic Mercury Compounds	3	23	30	6	10	4	8	1	15

S.I.C. code: 2869

Industry: Organic chemicals industry, NEC

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
322	Pentachlorophenol	5% (50,000 ppm)	3.0	0.10 (3.6)	0.12 (4.1)	0.14 (4.8)
	Acceptable for underground storage after treatment					
21	Ammonium Chromate		1.7			
22	Ammonium Dichromate		1.7			
36	Antimony Pentafluoride					
43	Antimony Trifluoride					
114	Chromic Acid					
128	Cuprous (Copper) Cyanide					
287	GB (Nerve Gas)					
243	Lewisite					
345	Potassium Dichromate		1.7			
379	Sodium Dichromate		1.7			

S.I.C. code: 2869

Industry: Organic chemicals industry, NEC

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
8	Acrolein					
105	Chlorine		6.5	6,484.59 (229×10^3)	8,155.29 (288×10^3)	10,307.38 (364×10^3)
106	Chlorine Trifluoride		6.5	0.04 (1.4)	0.05 (1.9)	.08 (2.6)
160	Dimethyl Sulfate					
165	Dinitrotoluene					
523	Gelatinized Nitrocellulose (PNC)					
221	Hydrogen Sulfide					
534	Nitrocellulose					
306	Nitrogen Mustard					
324	Perchloric Acid (72%)					
338	Picric Acid					
541	Smokeless Gunpowder					
387	Sodium Cyanide					
543	Sulfur Mustard					
107, 422	Tear Gas (CN)					
423	Tear Gas (CS)					
288	VX (Nerve Gas)					
	Not recommended for underground storage					
66	Bromine Pentafluoride					
253	Mercuric Chloride		3.0			
257	Mercury		3.0			
258	Organic Mercury Compounds		3.0	0.23 (8.1)	0.27 (9.4)	0.31 (10.8)

S.I.C. code: 2869

Industry: Organic chemicals industry, NEC

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
322	Pentachlorophenol	6	20	32	11	8	8	11	1	3

S.I.C. code: 2879

Industry: Agriculture chemicals, pesticides

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
13	Aldrin			3.54 (125)		
51	Arsenic Trioxide	3% (30,000 ppm)				
55	Benzene Hexachloride			0.37 (13)		
80	Cacodylic Acid	1% (10,000 ppm)				
87	Calcium Arsenate					
88	Calcium Arsenite					
490	Copper Acetoarsenite					
119	Copper Arsenate					
135	2, 4-D	20%		4,190.91 ($148x10^3$)		
136	DDD			679.61 ($24x10^3$)		
137	DDT	5% (50,000 ppm)		13,818.69 ($488x10^3$)		
491	Demeton			0.37 (13)		
149	Dieldrin			0.37 (13)		
170	Endrin			0.37 (13)		
495	Guthion			1.42 (50)		
496	Heptachlor	2.5% (25,000 ppm)		1,387.53 ($49x10^3$)		

S.I.C. code: 2879

Industry: Agriculture chemicals, pesticides (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
235	Lead Arsenate					
236	Lead Arsenite					
245	Magnesium Arsenite					
500	Manganese Arsenate					
322	Pentachlorophenol					
341	Potassium Arsenite					
376	Sodium Arsenate					
377	Sodium Arsenite					
382	Sodium Cacodylate					
453	Zinc Arsenate					
454	Zinc Arsenite					
	Acceptable for underground storage after treatment					
50	Arsenic Trichloride					
128	Cuprous (Copper) Cyanide					
239	Lead Cyanide					
386	Sodium Chromate	1.85% (18,500 ppm)		0.75 (26.5)		
	Underground storage of treatment products is optional					
91	Calcium Cyanide					
484	Chlordane	10% (100,000 ppm)		5,493.50 (194×10^3)		
162	Dinitro Cresols					

S.I.C. code: 2879

Industry: Agriculture chemicals, pesticides (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
221	Hydrogen Sulfide	5% (50,000 ppm)	3.7	3.23 (114)	3.85 (136)	4.62 (163)
274	Methyl Parathion		3.7	15.91 (562)	19.09 (674)	22.88 (808)
321	Parathion	0.1% (1,000 ppm)	3.7	23.53 (831)	28.23 (997)	33.84 (1,195)
344	Potassium Cyanide					
387	Sodium Cyanide					
	Not recommended for underground storage					
253	Mercuric Chloride					
255	Mercuric Nitrate					
257	Mercury					
285	Organic Mercury Compounds					

S.I.C. code: 2879

Industry: Agriculture chemicals, pesticides

		Percentage Distribution								
		Bureau of Census region								
ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
13	Aldrin	12	15	14	7	14	6	9	5	18
51	Arsenic Trioxide	1	7	14	7	30	21	9	5	6
55	Benzene Hexachloride	12	15	14	7	14	6	9	5	18
80	Cacodylic Acid		20	80						
87	Calcium Arsenate	3	2	8	7	16	16	36	9	3
490	Copper Acetoarsenite	1	7	14	7	30	21	9	5	6
135	2, 4-D	8	13	12	8	16	6	11	6	20
137	DDT	12	15	14	7	14	6	9	5	18
491	Demeton	12	15	14	7	14	6	9	5	18
149	Dieldrin	12	15	14	7	14	6	9	5	18
170	Endrin	12	15	14	7	14	6	9	5	18
495	Guthion	12	15	14	7	14	6	9	5	18
496	Heptachlor	12	15	14	7	14	6	9	5	18
235	Lead Arsenate	3	2	8	7	17	17	35	8	3
263	Lead Arsenite	1	7	14	7	30	21	9	5	6
341	Potassium Arsenite	1	7	14	7	30	21	9	5	6
377	Sodium Arsenite	1	7	14	7	30	21	9	5	6
382	Sodium Cacodylate		20	80						
454	Zinc Arsenite	1	7	14	7	30	21	9	5	6
	Acceptable for underground storage after treatment									
386	Sodium Chromate	1	6	12	13	19	18	19	2	10

S.I.C. code: 2879

Industry: Agriculture chemicals, pesticides

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Underground storage of treatment products is optional									
162	Dinitro Cresols		2	1	1	26			70	
221	Hydrogen Sulfide	1	1	1		3			1	93
278	Methyl Parathion	12	15	14	7	14	6	9	5	18
321	Parathion	12	15	14	7	14	6	9	5	18
	Not recommended for underground storage									
253	Mercuric Chloride	1	7	14	7	30	21	9	5	6
255	Mercuric Nitrate	1	7	14	7	30	21	9	5	6
257	Mercury	1	7	14	7	30	21	9	5	6
258	Organic Mercury Compounds	1	7	14	7	30	21	9	5	6

S.I.C. code: 2892

Industry: Explosives

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
517	Copper Acetylide					
520	Detonators and Primers					
529	Lead Azide			2.38 (84)		
530	Lead 2, 4 Dinitroresorcinate (LDNR)			6.51 (230)		
531	Lead Styphnate			6.77 (239)		
	Underground storage of treatment products is optional					
27	Ammonium Picrate, Dry					
28	Ammonium Picrate, Wet					
521	Diazodinitrophenol (DDNP)			12.83 (453)		
165	Dinitrotoluene (DNT)			458.74 (16,200)		
522	Dipentaerythritol Hexanitrate (DPEHN)			12.60 (455)		
525	Glycol Dinitrate			1,055.23 (37,265)		
532	Mannitol Hexanitrate			11.89 (420)		
534	Nitrocellulose			421.47 (14,884)		
307	Nitroglycerine			442.31 (15,620)		

S.I.C. code: 2892

Industry: Explosives (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
319	Pentaerythritol Tetranitrate (PETN)			887.14 (31,329)		
338	Picric Acid			895.04 (31,608)		
536	Potassium Dinitrobenzfuroxan (KDNBF)			9.46 (334)		
418	TNT			949.30 (33,524)		
542	Tetrazene			19.82 (700)		
	Not recommended for underground storage					
518	Copper Chlorotetrazole					
526	Gold Fulminate					
533	Mercuric Fulminate			1.19 (42)		
258	Organic Mercury Compounds					
537	Silver Acetylide					
538	Silver Azide					
539	Silver Styphnate					
540	Silver Tetrazene					

S.I.C. code: 2892

Industry: Explosives

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
529	Lead Azide		9	1	87		1		1	1
531	Lead Styphnate		9	1	87		1		1	1
	Underground storage of treatment products is optional									
521	Diazodinitrophenol (DDNP)		9	1	87		1		1	1
522	Dipentaerythritol Hexanitrate		9	1	87		1		1	1
532	Mannitol Hexanitrate		9	1	87		1		1	1
534	Nitrocellulose		6	4	39	48		1	2	
307	Nitroglycerine					42	19			39
319	Pentaerythritol Tetranitrate (PETN)	1	1	34	17	22	10	13	1	1
536	Potassium Dinitrobenzfuroxan (KDNBF)		9	1	87		1		1	1
418	TNT	1	1	34	17	22	10	13	1	1
	Not recommended for underground storage									
533	Mercuric Fulminate		9	1	87		1		1	1

S.I.C. code: 29

Industry: Petroleum and petrochemical industry

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
322	Pentachlorophenol					
	Acceptable for underground storage after treatment					
343	Potassium Chromate					
345	Potassium Dichromate					
386	Sodium Chromate					
379	Sodium Dichromate					
	Underground storage of treatment products is optional					
221	Hydrogen Sulfide			1.12×10^6 (39.557×10^6)		
	Not recommended for underground storage					
253	Mercuric Chloride					

S.I.C. code: 29

Industry: Petroleum and petrochemical industry

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
81	Cadmium	4	12	20	8	14	8	14	4	16
	Acceptable for underground storage after treatment									
50	Arsenic Trichloride	1	8	16	5	3	3	48	3	13
239	Lead Cyanide	1	10	17	5	2	3	42	4	16
120	Copper Cyanide	1	10	17	5	2	3	42	4	16
	Not recommended for underground storage									
253	Mercuric Chloride	1	6	9	1	12	10	55	2	4

S.I.C. code: 31

Industry: Leather tanning

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide					
322	Pentachlorophenol					
	Acceptable for underground storage after treatment					
343	Potassium Chromate			7.93 (280)		
345	Potassium Dichromate					
386	Sodium Chromate			264.54 (9,342)		
379	Sodium Dichromate					
	Not recommended for underground storage					
253	Mercuric Chloride					

S.I.C. code: 31

Industry: Leather tanning

		Percentage Distribution								
		Bureau of Census region								
ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
386	Sodium Chromate	22	29	29	3	8	5	1		3

S.I.C. code: 33

Industry: Primary metals

		Percentage Distribution								
		Bureau of Census region								
ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
51	Arsenic Trioxide		3	1	7	1	1	10	70	7
	Underground storage of treatment products is optional									
387	Sodium Cyanide	4	19	48	2	9	3	7	6	2
	Not recommended for underground storage									
257	Mercury		3	1	7	1	1	10	70	7

S.I.C. code: 331

Industry: Cold finishing

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
386	Sodium Chromate	0.025% (250 ppm)		16,367.22 ($578x10^3$)		
	Underground storage of treatment products is optional					
387	Sodium Cyanide	.00125% (12.5 ppm)		138.24 (4,882)		

S.I.C. code: 331

Industry: Blast furnaces

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
387	Sodium Cyanide	.0045% (45 ppm)		0.07 (2.6)		

S.I.C. code: 3312

Industry: Coke plant wastes

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
387	Sodium Cyanide	.006% (60 ppm)		1.33 (46.8)		

S.I.C. code: 333

Industry: Nonferrous (Brass mill wastes)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
379	Sodium Dichromate	1% (10,000 ppm)	1.7	92.29 (3,259)	100.41 (3,546)	109.28 (3,859)

S.I.C. code: 333

Industry: Smelting and refining of metals, NEC

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide					
81	Cadmium					
85	Cadmium Oxide					
	Acceptable for underground storage after treatment					
82	Cadmium, Powdered					
128	Cuprous (Copper) Cyanide					
370	Silver Cyanides					
386	Sodium Chromate			0.04 (1.4)		
379	Sodium Dichromate			4.93 (174)		
	Underground storage of treatment products is optional					
91	Calcium Cyanide					
293	Nickel Carbonyl					
344	Potassium Cyanide					
387	Sodium Cyanide					
457	Zinc Cyanide					
	Not recommended for underground storage					
253	Mercuric Chloride					
256	Mercuric Sulfate					
257	Mercury					

S.I.C. code: 3471

Industry: Metal plating and finishing

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
81	Cadmium	2.3% (23,000 ppm)	14	15.86 (560)	30.50 (1,077)	58.67 (2,072)
85	Cadmium Oxide	3%	14	3.20 (113)	6.14 (217)	11.84 (418)
481	Cadmium Sulfate		14			
	Acceptable for underground storage after treatment					
82	Cadmium, Powdered		14			
84	Cadmium Cyanide	5.77% (57,700 ppm)	14	209.35 (7,393)	402.58 (14,217)	774.16 (27,339)
114	Chromic Acid					
128	Cuprous (Copper) Cyanide					
129	Cyanides					
239	Lead Cyanide					
295	Nickel Cyanide					
343	Potassium Chromate					
345	Potassium Dichromate		14	322.93 (11,404)	621.77 (21,957)	1,197.17 (42,277)
370	Silver Cyanides	4.55% (45,500 ppm)				
386	Sodium Chromate	0.04% (400 ppm)				
379	Sodium Dichromate		14	10,763.97 (380,124)	20,725.10 (731,896)	39,904.41 (1.409×10^6)
480	Cadmium Potassium Cyanide					

S.I.C. code: 3471

Industry: Metal plating and finishing

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
120	Copper Cyanide	5.4% (54,000 ppm)	2.9	12.49 (441)	14.41 (509)	16.62 (587)
	Underground storage of treatment products is optional					
91	Calcium Cyanide					
324	Perchloric Acid (72%)					
344	Potassium Cyanide					
387	Sodium Cyanide					
457	Zinc Cyanide	5% (50,000 ppm)				
	Not recommended for underground storage					
66	Bromine Pentafluoride					
253	Mercuric Chloride					

S.I.C. code: 3471

Industry: Metal plating and finishing

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
81	Cadmium	13	28	32	5	5	2	4	1	10
	Acceptable for underground storage after treatment									
84	Cadmium Cyanide	13	28	32	5	5	2	4	1	10
370	Silver Cyanides	11	18	38	5	5	1	4	1	17
386	Sodium Chromate	11	18	38	5	5	1	4	1	17
379	Sodium Dichromate	11	18	38	5	5	1	4	1	17
120	Copper Cyanide	11	18	38	5	5	1	4	1	17
	Underground storage of treatment products is optional									
457	Zinc Cyanide	11	18	38	5	5	1	4	1	17

S.I.C. code: 36

Industry: Battery manufacture, electronics, magnetic tape production

		Percentage Distribution								
		Bureau of Census region								
ID no.	Waste name	(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
85	Cadmium Oxide	3	24	29	11	10	3	6	1	13
	Acceptable for underground storage after treatment									
22	Ammonium Dichromate	17	33	16	12	8	2	6		6
114	Chromic Acid	17	33	16	12	8	2	6		6
	Not recommended for underground storage									
257	Mercury	14	34	17	4	5	2	3	4	17

S.I.C. code: 37

Industry: Aircraft plating wastes

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
129	Cadmium Cyanide	1.5% (15,000 ppm)		119.64 (4,225)		
	Underground storage of treatment products is optional					
387	Sodium Cyanide	8.5% (85,000 ppm)		940.12 (33,200)		

S.I.C. code: 37

Industry: Aircraft plating wastes

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
129	Cadmium Cyanide	12	16	12	9	6	1	10	2	32
	Underground storage of treatment products is optional									
387	Sodium Cyanide	12	16	12	9	6	1	10	2	32

S.I.C. code: 38

Industry: Professional, Scientific, and Control Instruments - Photographic

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
81	Cadmium					
83	Cadmium Chloride					
	Acceptable for underground storage after treatment					
21	Ammonium Chromate		2.1	0.91 (32.2)	0.99 (35.0)	1.10 (38.8)
22	Ammonium Dichromate		2.1			
82	Cadmium, Powdered					
479	Cadmium Nitrate					
114	Chromic Acid		2.1			
345	Potassium Dichromate		2.1			
	Not recommended for underground storage					
253	Mercuric Chloride					
257	Mercury					
258	Organic Mercury Compounds					

S.I.C. code: 49

Industry: Electronic services and combined utilities

ID no.	Waste name	Percentage Distribution								
		Bureau of Census region								
		(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
50	Arsenic Trichloride	5	22	6	4	32	24		7	

S.I.C. code: 9711

Industry: National security

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
81	Cadmium	16%		16.37 (578)		
85	Cadmium Oxide	3%		3.79 (134)		
135	2,4-D	50%				
376	Sodium Arsenate	45%				
	Underground storage of treatment products is optional					
423	Tear Gas, Irritant (CS)					

S.I.C. code: 9711

Industry: National security

ID no.	Waste name	Percentage Distribution Bureau of Census region								
		(1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Underground storage of treatment products is optional									
423	Tear Gas, Irritant (CS)		14	19		2	5	25	14	21

S.I.C. code: ______

Industry: Cooling tower blowdown

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage after treatment					
386	Sodium Chromate			3,273.44 (115.6×10^3)		

S.I.C. code:

Industry: Cooling tower blowdown

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage after treatment									
386	Sodium Chromate	4	13	15	5	25	10	15	3	10

S.I.C. code: ____________________

Industry: Coal combustion wastes

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide	.0008% (8 ppm)		240.69×10^3 (8.5×10^6)		
	Not recommended for underground storage					
257	Mercury			35.79 (1,264)		

S.I.C. code: ____

Industry: Coal combustion wastes

ID no.	Waste name	Percentage Distribution Bureau of Census region (1) NE	(2) MA	(3) ENC	(4) WNC	(5) SA	(6) ESC	(7) WSC	(8) M	(9) W
	Acceptable for underground storage with no treatment									
51	Arsenic Trioxide	2	15	38	7	20	15		4	
	Not recommended for underground storage									
257	Mercury	2	15	38	7	20	15		4	

S.I.C. code: ______________________

Industry: DOD Storage

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment:					
13	Aldrin			0.31 (11)		
55	Benzene Hexachloride			1,418.00 (50,076)		
85	Cadmium Oxide			0.01 (0.4)		
490	Copper Acetoarsenite			0.33 (11.7)		
135	2,4-D			1.35 (47.6)		
136	DDD			1,418.00 (50,076)		
137	DDT			35,488.72 (1,253,266)		
491	Demeton			78.15 (2,760)		
149	Dieldrin			0.03 (1)		
170	Endrin			0.03 (1)		
495	Guthion			234.44 (8,279)		
496	Heptachlor			18.69 (660)		
235	Lead Arsenate			0.11 (3.9)		
376	Sodium Arsenate					
	Acceptable for underground storage after treatment					
114	Chromic Acid			0.33 (11.8)		

S.I.C. code: ____________________

Industry: D O D Storage (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage after treatment					
128	Cuprous (Copper) Cyanide			0.03 (1)		
520	Detonators and Primers					
521	Diazodinitrophenal (DDNP)(as munitions)			4,552.81 (160,780)		
165	Dinitrotoluene (DNT) (as munitions)			14,836.63 (523,948		
522	Dipentaerythritol Hexanitrate (DPEHN) (as munitions)			4,552.81 (160,780)		
287	GB (nonpersistent Nerve Gas)					
523	Gelatinized Nitrocellulose (PNC) (as munitions)			14,558.44 (514,124)		
529	Lead Azide			1,694.43 (59,838)		
530	Lead 2,4 Dinitroresorcinate			2,325.70 (82,131)		
531	Lead Styphnate			2,408.33 (85,049)		
243	Lewisite					
532	Mannitol Hexanitrate (as munitions)			4,304.49 (152,011)		
533	Mercuric Fulminate (as munitions)			1,673.14 (59,086)		
307	Nitroglycerine (as munitions)			14,298.97 (504,961)		
319	Pentaerythritol Tetranitrate(PETN) (as munitions)			12,993.67 (458,865)		

S.I.C. code: ____________________

Industry: D O D Storage (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage after treatment					
338	Picric Acid (as munitions)			13,109.69 (462,962)		
343	Potassium Chromate			0.03 (1.)		
345	Potassium Dichromate			0.50 (17.8)		
536	Potassium Dinitrobenzfuroxan (KDNBF)(as munitions)			3,358.14 (118,591)		
370	Silver Cyanides					
541	Smokeless Gunpowder (as munitions)					
386	Sodium Chromate			5.58 (197.)		
379	Sodium Dichromate			0.09 (3.2)		
418	TNT (as munitions)			13,904.24 (491,021)		
542	Tetrazene (as munitions)			7,262.17 (256,460)		
	Underground storage of treatment products is optional					
525	Glycol Dinitrate (as munitions)			15,455.67 (545,809)		
534	Nitrocellulose (as munitions)			13,624.49 (481,142)		
91	Calcium Cyanide			0.08 (3)		
484	Chlordane			0.76 (27)		

S.I.C. code: ______________________________

Industry: D O D Storage (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Underground storage of treatment products is optional					
106	Chlorine Pentafluoide			0.49 (17.4)		
521	Diazodinitrophenol (DDNP)(nonmunitions)			9.12 (322)		
165	Dinitrotoluene(DNT) (nonmunitions)			2,750.66 (97,138)		
522	Dipentaerythritol Hexanitrate(DPEHN) (nonmunitions)			9.12 (322)		
523	Gelatinized Nitrocellulose (PDN) (nonmunitions)			2,699.06 (95,316)		
525	Glycol Dinitrate (DDN)(nonmunitions)			2,889.32 (102,035)		
532	Mannitol Hexanitrate (nonmunitions)			8.61 (304)		
274	Methyl Parathion			2,695.86 (95,203)		
534	Nitrocellulose (nonmunitions)			2,525.93 (89,202)		
306	Nitrogen Mustard					
307	Nitroglycerine (nonmunitions)			2,650.98 (93,618)		
321	Parathion			898.61 (31,734)		
505	Pentaborane			145.07 (5,123)		
319	Pentaerythritol Tetranitrate(PETN) (nonmunitions)			2,429.09 (85,782)		
338	Picric Acid (nonmunitions)			2,450.78 (86,548)		

S.I.C. code: ______

Industry: D O D Storage (continued)

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Underground storage of treatment products is optional					
344	Potassium Cyanide					
536	Potassium Dinitrobenzfuroxan (KDNBF) (nonmunitions)			6.71 (237)		
541	Smokeless Gunpowder (nonmunitions)					
387	Sodium Cyanide			0.39 (13.8)		
543	Sulfur Mustard					
418	TNT (nonmunitions)			2,599.30 (91,793)		
107, 422	Tear Gas (CN)			414.02 (14,621)		
423	Tear Gas, Irritant (CS)			413.43 (14,600)		
542	Tetrazene (nonmunitions)			14.55 (514)		
288	VX (Persistent Nerve Gas)					
	Not recommended for underground storage					
66	Bromine Pentafluoride			0.36 (12.8)		
533	Mercuric Fulminate (nonmunitions)			3.34 (118)		

S.I.C. code: ____________________

Industry: Federal, State, and Municipal storage

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3) 1975	1980	1985
	Acceptable for underground storage with no treatment					
13	Aldrin					
51	Arsenic Trioxide			0.14 (4.9)		
55	Benzene Hexachloride			1.44 (51)		
87	Calcium Arsenate			0.03 (1)		
135	2,4-D			4,866.98 (171,875)		
136	DDD					
137	DDT			46.24 (1,633)		
491	Demeton					
149	Dieldrin					
170	Endrin					
495	Guthion					
496	Heptachlor					
235	Lead Arsenate			0.03 (1)		
	Underground storage of treatment products is optional					
484	Chlordane			1.02 (36)		
274	Methyl Parathion					
321	Parathion			15.38 (543)		
	Not recommended for underground storage					
254	Mercuric Cyanide					

S.I.C. code: ____________________

Industry: Industrial storage

ID no.	Waste name	Waste gen factor	% incr per yr	Volume m^3 (ft^3)		
				1975	1980	1985
	Acceptable for underground storage with no treatment					
51	Arsenic Trioxide					
80	Cacodylic Acid			159.28 (5,625)		
87	Calcium Arsenate					
88	Calcium Arsenite					
490	Copper Acetoarsenite					
119	Copper Arsenate					
235	Lead Arsenate			1.65 (58.4)		
236	Lead Arsenite					
245	Magnesium Arsenite					
500	Manganese Arsenate					
341	Potassium Arsenite					
382	Sodium Cacodylate			106.19 (3,750)		
453	Zinc Arsenate					
454	Zinc Arsenite					
	Acceptable for underground storage after treatment					
50	Arsenic Trichloride					
	Underground storage of treatment products is optional					
61, 505	Boron Hydrides					

APPENDIX C

DETECTION, MONITORING, AND CONTROL TECHNOLOGY

CONTROL/SAMPLING SYSTEMS

Instrument or Technique	Filtration (fiber, paper, activated charcoal, membranes, etc.).
Operating Principle	Fluid flow through coarse medium deposites particulate load.
Operating Range	Submicron and larger - dependent on type of filter, fluid load, and flow time.
Limitations	Limited quantification - poor to no qualification size-grading.
Reliability	Very good, with proper maintenance.
Availability	Many filtration systems readily available.
Comments/Description	Filtration systems provide excellent sampling capability and very good control (cleaning) capability. It is necessary to service (clean, replace, etc.) the filter media periodically for the system to function well. Identification of particulates can be made using other techniques.

CONTROL/SAMPLING SYSTEMS

Instrument or Technique	Settling (dust jars, adhesives).
Operating Principle	Gravitational deposition of particulates (usually on a "holding" media such as liquid or adhesive).
Operating Range	Particulates commonly greater than micron size.
Limitations	Limited quantification, poor qualification. In a mobile fluid size-grading is normal.
Reliability	Excellent, with proper maintenance.
Availability	Many commercial and "home built" systems.
Comments/Description	Settling systems provide simple, cheap, and limited sampling capability. Rough quantification is possible; however, qualification normally requires other systems. Problems of separating particulates from "holding" material are inherent in system.

CONTROL/SAMPLING SYSTEMS

Instrument or Technique	Inertial Collectors (impactors, impingers, cyclones).
Operating Principle	Impactors - higher mass particles lose momentum on contact with deflector. Centrifuges - particulates spin-out of circular fluid flow.
Operating Range	Generally 0.5-50 micron size - increased effectiveness using multiple stages. Dependent on velocity: increase velocity = decrease particle size.
Limitations	Quantifies within range. Limits sizing by using multiple stages.
Reliability	Good - high abrasion of impact surfaces common. Dependent on unit complexity and maintenance procedure.
Availability	Many commercial units of several designs and efficiencies are available.
Comments/Description	Inertial collectors are good for continuous sampling/cleaning operations of particulates in heavy-load fluids. Problems of efficient recovery and abrasion are common.

CONTROL/SAMPLING SYSTEMS

Instrument or Technique	Precipitators
Operating Principle	Electrostatic-charged particles in a strong electric field are attracted to poles. Thermal-airborne particles are driven to cold substrate in a temperature gradient environment.
Operating Range	All sizes - submicron ranges up to 3 or 4 micron size.
Limitations	Particles must possess electrical charge (inherent or induced) small volume.
Reliability	High efficiency (up to 98%) good reliability with maintenance excellent reliability of performance.
Availability	Commercially available (several types & sizes).
Comments/Description	Electrostatic precipitators are highly efficient cleaning/sampling devices up to moderate loads. In general, size, efficiency, and cost rise together. Thermal precipitators are generally slow, low volume separators.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Photometric Analyzers (visual opacity (Haze), particle illumination).
Operating Principle	Light scattered by particulates is related to mass and concentration.
Operating Range	0.2 micron and larger.
Limitations	Quantitative analysis, rarely qualitative.
Reliability	Very Good.
Availability	Commercial and experimental units.
Comments/Description	Photometric analyzers are typically quantitative detectors. Have long distance capability using laser. Limited qualitative analysis with ultraviolet infrared and other frequency sources. Active experimentation should develop more efficient, specific, and effective instrumentation.
Instrument or Technique	Tribo-electric.
Operating Principle	"Light" emitted from heat of friction.
Operating Range	Unknown
Limitations	Unknown
Reliability	Unknown
Availability	Under development.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Condensation Nuclei (counters).
Operating Principle	Particles injected into super-saturated water vapor will attract and condense the water.
Operating Range	Submicron and larger. Degree of saturation controls particle size (inversely).
Limitations	Limited quantification. Intermittent use. Qualification by other means.
Reliability	Good reliability within design limits.
Availability	Commercially available.
Comments/Description	Condensation sampling equipment is efficient on a selective basis. Substitution of vapor compounds may allow specific particle capture and research in this direction is assumed. Additional experimentation should provide many improvements and increase overall usability and applications.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Electric Mobility
Operating Principle	Induced charge on particles will cause conductivity change - measurable.
Operating Range	Submicron and larger.
Limitations	Quantification probable. Qualification - probably limited.
Reliability	Unknown
Availability	Under development.
Comments/Description	Concept is sound. State of present development and future potential unknown.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Acoustical Techniques.
Operating Principle	Accelerated particles ($\geq$100 m/sec) entering hexacavity make audible pressure pulse.
Operating Range	Not well defined.
Limitations	?
Reliability	Unknown
Availability	Under development.
Comments/Description	Concept is proven. Additional experimentation required.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Electrometer Deflection
Operating Principle	Particles having a natural charge will deflect from electrometer probe allowing measurement.
Operating Range	Sensitivity will depend on equipment.
Limitations	Qualitative analysis of equally charged particles is not presently possible.
Reliability	Good potential.
Availability	Experimental system in use.
Comments/Description	May give rapid quantification and qualification (within limitations) of representative particulates. Research and development continuing.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Atomic Absorption Spectrometry
Operating Principle	The sample is converted into an atomic vapor and the absorption of the atomic vapor is measured at a selected wavelength which is characteristic for each individual element.
Applications	Specific testing for particulates and water streams.
Limitations	Not suitable for organic compounds. Usually must be in liquid form or in solution.
Reliability	Very reliable.
Availability	Presently available from commercial sources.
Comments	Not practical at present for automation. Some instruments are economical.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Flame Emission Spectrometry
Operating Principle	The sample is vaporized and excited in a flame to emit radiations that are characteristic for each element.
Applications	Specific testing for particulates and water streams.
Limitations	Not suitable for organic compounds. Usually must be in liquid form or a solution.
Reliability	Very reliable for alkali and alkaline earth metals.
Availability	Presently available from commercial sources.
Comments	Not practical at present for automation. These instruments are economical.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Emission Spectrometry
Operating Principle	Utilizes the characteristic radiation produced when materials are introduced into thermal or electric sources.
Applications	Specific testing for particulates and water streams.
Limitations	Not suitable for organic compounds. Some samples may need special preparation which usually does not take very much time.
Reliability	Very reliable.
Availability	Presently available from commercial sources.
Comments	These instruments are expensive. Ideally adaptable to computer readout. Can analyze over 40 elements in a very short period.

PARTICULATE MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Turbidimetry
Operating Principle	Measurement is made of the intensity of light transmitted through a medium.
Applications	Testing of gas particulates and water streams.
Limitations	May not be specific.
Reliability	Can note changes very quickly.
Availability	Presently available from commercial sources.
Comments	Ideal for automation. Instruments are economical.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Colorimetric Detectors
Operating Principle	Certain compounds react chemically (oxidation etc) to cause a visible color change.
Limitations	Rough quantification is normal, but lower limits are usually well-defined. Manual single-test apparatus.
Application(s)	Specific testing of hazardous vapor, particulates, and gases.
Reliability	Very reliable within specified limits.
Availability	Presently available from commercial sources.
Comments	These detectors provide excellent periodic or emergency analysis of a confined environment. Used in conjunction with continuous, automated instrumentation they can give fast specific detection and area isolation capability.

Instrument or System	Glycol Detector
Operating Principle	Certain compounds react chemically (oxidation etc) to cause a visible color change.
Limitations	± 1 ppm (limit not well defined).
Application	Detection of glycol vapor
Reliability	Experimental - good potential.
Availability	Under development for NASA.
Comments	Formaldehyde gives same color change - other aldehydes give different colors.

Colorimetric Dectors (continued)

Instrument or System	Hydrogen Sulfide, Chlorine, Mercury Vapor, Hydrogen Cyanide, Boron Hydrides, Chromic Acid, Lead.
Operating Principle	Certain compounds react chemically (oxidation etc) to cause a visible color change.
Limitations	Hydrogen Sulfide - 0-50 ppm - immediate response. Chlorine - 0-20 ppm - immediate response. Mercury Vapor - 0-1.0 mg/m^3. Hydrogen Cyanide - 1-65 ppm. Boron Hydrides - 1.0 ppm penta and deca compounds. Boron Hydrides - 3.0 ppm diborane. Chromic Acid - 0.1-0.2 mg/M^3. Lead - 0.05-4.2 mg/M^3.
Application(s)	Detection of each.
Reliability	Excellent - Used as directed.
Availability	Commercially available.
Comments	Color Change - Magnitude allows rough concentration analysis.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Hydrogen Detectors
Operating Principle	H_2 sensitive catalyst to heat-activate thermochromic paint and cause color change.
Limitations	0.5 to 4% in air.
Application(s)	Remote or portable H_2 monitoring systems and can be adapted to other combustible gas systems.
Reliability	Good reliability within limits.
Availability	Commercially available.
Comments	Due to its explosive characteristics most wastes which evolve H_2 gas in quantity could not be stored in an underground facility. However, many products and by-products may evolve H_2 in measurable amounts, and it is expected that finite changes in H_2 concentrations could be an important indicator of leakage in a restricted environment.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Microwave Spectroscopy (NASA).
Operating Principle	Different gases absorb different microwave-lengths.
Limitations (range)	Only gases composed of polar molecules can be identified - laboratory system as developed.
Application(s)	Gas analysis including mixtures and compounds - both quantitative and qualitative.
Reliability	Very good - should improve with more technology.
Availability	System components are commercially available.
Comments	System was developed for NASA and has proven capability. Research on duel resonance techniques should improve overall quality and performance.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Mass Spectroscopy (system).
Operating Principle	Different ionized masses (molecules) can be separated using deflection fields and measured using electron multipliers.
Limitations (range)	Molecule identification scan rate must be long enough to confirm identification. Very low concentrations require longer scan times.
Application(s)	Excellent qualification of elements making up air stream. Can be used for identifying gases and particulates.
Reliability	Very good to excellent: using good standards and techniques.
Availability	Several commercial units available.
Comments	Spectroscopic analysis provides excellent identification and adequate quantification of component elements in an airstream. The basic system can be expanded to analyze most (possibly all) desired elements.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Cycloidal-Focusing Mass Spectrometer (NASA).
Operating Principle	As described with addition of vacuum system for sampling.
Limitations (range)	Analysis of vapors in the 3 to 100 AMU range (as developed). Limited accuracy in measuring low concentrations and slower response time.
Application(s)	Continuous sampling with very fast response time (<1.0 sec).
Reliability	Very reliable as tested.
Availability	Developed for and used by NASA.
Comments	This monitoring system as developed for NASA is quite compact and may provide a portable gas detection system.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Non-magnetic Flight Mass Specrometer (NASA).
Operating Principle	Partial pressure analyzer. Ion separation using combined radio-frequency and direct-current field.
Limitations (range)	Quantify and qualify from 2 to 600 atomic mass units (AMU). Tested to 300 AMU. Sensitivity to 10^{-10} torr,-60 second scan.
Application(s)	Mass no. vs partial press. identifies chemical nature of constituents - can be used for continuous automated sampling.
Reliability	Highly reliable up to 300 AMU. Untested from 300-600 AMU.
Availability	Prototype developed for NASA - Experimental.
Comments	This unit has very good potential for providing accurate continuous sample analysis within the AMU range of most hazardous gases or their derivatives.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Trace Gas Analysis (system).
Operating Principle	Cryogenic airstream fractionating; chromatograph analysis; mass spectrometry analysis.
Limitations (range)	System capable of identifying some 100 compounds in approximately 90 minutes. Quantify and qualify.
Application(s)	Lab. system for isolating and identifying compounds. Not automated, plus requires highly skilled technicians.
Reliability	Highly reliable using good laboratory technique.
Availability	System utilizes commercial sampling units which are all presently available.
Comments	This system is best suited to laboratory analysis and might be a worthwhile back up or check system for on-site monitors. Individual and unique automated and semi-automated systems have been developed using gas chromatographs to mass spectrometers to infrared spectrometers - none commercial.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Photoionization Source Mass Spectrometer.
Operating Principle	Ionization by ultraviolet light.
Limitations (range)	Slower than more common ionization techniques, but better determination of complex molecules. Can detect in the 10 to 100 ppm range.
Application(s)	Best for accurate analysis of gas composition - especially high molecular weight gases.
Reliability	Generally very reliable for identification of complex molecules.
Availability	Single prototype unit - experimental.
Comments	Technique is very promising for specific gas analysis with high qualification accuracy due to simplified spectra.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Contaminant Sensor (mass spectrometer).
Operating Principle	Differential separation of airstream using accumulator cells having different sorbencies.
Limitations (range)	Detection in the 0.5 to 5 ppm range Quantification if over 100 ppm. Range of prototype is 2-200 AMU.
Application(s)	Low level (concentration) detection of hazardous gases.
Reliability	Very good reliability as developed.
Availability	Components of system are available commercially.
Comments	This system is very good for relatively fast detection of many gases within an airstream and should be quite useful in monitoring a closed or semi-closed environment.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or Technique	Gas Chromatography
Operating Principle	Mixtures are separated on a suitable column. The components are then identified by a suitable detector.
Applications	Quantitative and qualitative analysis of gases and liquids.
Limitations	Must be vaporizable at a reasonable temperature (< 400°C). May need more than one carrier gas, column, and detector.
Reliability	Very reliable. Needs good control of temperature and pressure.
Availability	Presently available from commercial sources.
Comments	Can be automated. Prices vary from economical to moderate. Ideal for use in conjunction with a mass spectrograph.

GAS MONITORS

DETECTION SYSTEMS/TECHNIQUES

Instrument or System	Specific Gas Spectrometer (NASA).
Operating Principle	Heliarc combustion of gases produces unique light emissions. Components of a gas mixture can be identified using photomultipliers and spectrometer analysis.
Limitations	As developed: detects O_2 and H_2 in Argon carrier to less than 5 ppm.
Applications	Used to monitor impurities in inert welding gases.
Reliability	The technique has proven reliability as developed.
Availability	The technology is available and the necessary components are commercially produced.
Comments	Although limited as developed, the technique holds excellent potential for being expanded to monitor any, or possibly all components of an airstream (gaseous elements). The addition of photomultipliers responsive to individual gas emission lines might make a valuable airstream monitor.

GAS AND PARTICULATE

MONITORING AND DETECTION TECHNIQUES

Instrument or Technique	Visible Spectrometry
Operating Principle	Certain compounds react chemically (oxidation etc) to cause a visible color change.
Applications	Specific monitoring and/or testing of gas, particulates, vapor, and water streams.
Limitations	Some methods are time consuming. There may be interferences by some compounds.
Reliability	If interferences are screened, these instruments are reliable.
Availability	Presently available from commercial sources.
Comments	Can be automated for the detection of some compounds. Instruments are economical. Very versatile.

GAS AND PARTICULATE

MONITORING AND DETECTION TECHNIQUES

Instrument or Technique	Ultraviolet Spectrometry
Operating Principle	Certain compounds react chemically to cause a change in ultraviolet absorption. Usually 170-400 millimicrons.
Applications	Specific testing of vapor, particulates, gas or water streams.
Limitations	Some procedures are time consuming. There may be interferences by some compounds.
Reliability	If the interferences are screened, this method can be very reliable.
Availability	Presently available from commercial sources.
Comments	Can be automated for the detection of some compounds. Instruments are economical and versatile.

GAS AND PARTICULATE MONITORING AND DETECTION TECHNIQUES

Instrument or Technique	Infrared Spectrometry
Operating Principle	The study of absorption spectra of compounds between the approximate wavelengths of 0.8 to 1,000 microns. Practically this study is usually made between 2 and 50 microns.
Applications	Specific and general testing of vapor, particulates, gas and liquids.
Limitations	Usually better for organic compounds. Special treatment needed if water is present or if the material being tested is a solid.
Reliability	Usually very reliable.
Availability	Presently available from commercial sources.
Comments	Ideal for automated monitoring of gases. Some instruments are economical.